Health in urban late medieval North-West Europe: a bioarchaeological study of Caen, Canterbury and Ghent

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Abstract

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M.J.C. Gernay

Over half of the global population currently lives in an urban environment and this is still increasing rapidly in developing countries. This thesis aims to provide a comparative picture of health in the rapidly developing urban centres in late medieval NW Europe - here defined as northern France, England and Belgium - through bioarchaeological analysis. This study focused on macroscopic methods and "stress indicators" (cribra orbitalia, dental enamel hypoplasia, adult stature and periosteal reaction on the tibiae) as a proxy for health and sanitation in these populations and respiratory disease (periosteal rib lesions and maxillary sinusitis) as a proxy for air quality.

A 100 adult skeletons were analysed from the Darnétal cemetery of Caen (12th – 18th century AD), northern France, which had a reputation for poor sanitation. A further 100 adult skeletons were analysed from the cemetery of St. Gregory's priory in Canterbury (12th – 16th century AD), whose economy is based around entertaining pilgrims and travellers. Lastly, The St. Pieter parish in Ghent (12th – 18th century AD) occupies a unique position on the edge of the town and 83 adult skeletons were analysed from this site.

The skeletal evidence did not reflect the differences in sanitary conditions expected originally. Similar results were recorded for average adult stature estimates as well as the prevalence of cribra orbitalia, and dental enamel hypoplasia across the sites. It has been suggested that urban centres throughout the region may have been challenged to provide a healthy living environment.

High prevalence rates of maxillary sinisusitis (Caen: 71%, Canterbury: 64%, and Ghent: 61%) and high prevalence rates of periosteal reaction on the ribs in Caen (63%) and Canterbury (63%) suggest significant levels of air pollution in these populations. The unusually high levels of rib lesions in Caen and Canterbury set the agenda for further research into their occurence and the development of recording standards.

Lastly, the historical differences between the towns, and the location of the St Pieter parish, challenge the simplistic division of settlements into 'urban' and 'rural' types. It reveals the perspective for a more nuanced interpretation of urbanisation in NW Europe.

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Statement of Copyright

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Dedication

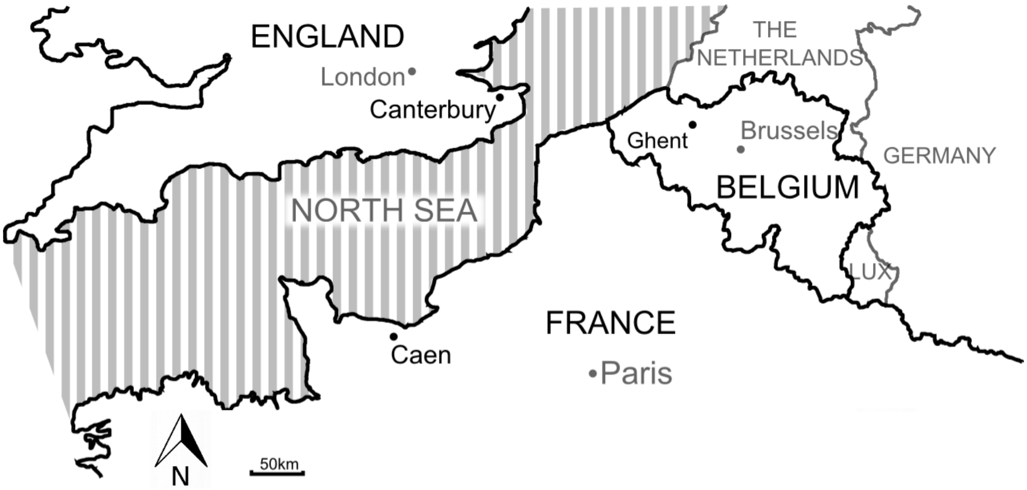
I would like to dedicate this PhD to my parents and brothers
for their patience and support throughout my time in England

1.1 Introduction

In the 20th century, there was a significant increase in urbanisation throughout the world. In 1900 only 15% of the global population was living in an urban centre (Satterthwaite, 2007). In contrast, over 50% of the world's population is now estimated to live in towns and cities and this is expected to increase to 70% by 2050 (Bettencourt and West, 2010; Cyril et al., 2013). However, there are large disparities in the level of urbanisation around the world. In Europe, approximately 75% of the population lives in an urban environment (Appu, 2012). In developing countries, on the other hand, a much lower percentage (44%) of the population is living in urban areas (Cyril et al., 2013).

Urbanisation has been associated with increased opportunities for economic growth and diversification as well as better access to services as education and health care (Cyril et al., 2013). However, it is also associated with an increase in crime, increased prevalence of certain diseases and increased exposure to air pollution (Dahly and Adair, 2007). In the developed world, heavy investment in infrastructure for supplying potable water and disposing of waste in combination with tight regulation has been able to create 'healthy cities', where living in an urban environment is associated with health benefits (Rydin et al., 2012). In rapidly developing cities in low and middle income countries, infrastructure is often inadequate, resulting in poor living conditions and thus adverse health outcomes (Rydin et al., 2012).

Figure 1.1: NW Europe with the sites used in this research



Urban settlements that were present during the Roman period in NW Europe largely disappeared after the fall of the Roman Empire in the 5th century AD (Palliser, 2000a). The urban revival in this region started in the 9th century AD (Nicholas, 1992; Neveux, 1997; Palliser, 2000b; Clark, 2009; Blockmans, 2010; Gauthiez, 2010). Over the next four centuries, the population increased exponentially and by 1300 an estimated 10-15% of the European population lived in an urban environment (Hubert, 2004; Clark, 2009). This does, however, hide a large variability between the different regions. Apart from Italy, the medieval County of Flanders became the most densely urbanised region of Europe (Hubert, 2004; Clark, 2009; van Bavel, 2010). This research aims to compare health in people who lived in urban contexts in Ghent in Flanders, Belgium with two towns from neighbouring regions: Caen in Normandy, France and Canterbury in Kent, England (see) through the analysis of human skeletal remains from cemeteries from those towns.

This chapter first sets out the aims, objectives and hypothesis for this research. It will then explore the significance of this research. As bioarchaeology has developed in different ways and at varying speeds in each country, this is followed by a summary of development in each country. Definitions of some of the concepts and assumptions regarding the study of health used in this research are outlined, and the structure of the thesis.

1.2 Aims and objectives

The main aim of this thesis is to provide a comparative picture of late medieval urban health in culturally and geographically closely related regions of North-West Europe.

In order to achieve this aim, skeletal collections from Caen (Normandy), Canterbury (Kent) and Ghent (Flanders) are examined. In particular, this research focuses on the macroscopic analysis of indicators of adaptation and respiratory disease.

1.3 Hypotheses

- The relative lack of industry in Canterbury may have had a positive impact on the health of its inhabitants.
- Poor sanitation, frequent warfare, economic collapse and the plague had a negative impact on health in Caen.
- Early industrial specialisation and the suburban nature of the living environment in Ghent led to indoor and outdoor pollution which negatively impacted health

1.4 Research questions

- Are there any demographic differences in health within and between the populations?
- Did poor sanitary conditions lead to increased levels of skeletal indicators (dental enamel hypoplasia, cribra orbitalia, periosteal reaction on the tibiae and a shorter stature)?
- Did poor air quality lead to high levels of respiratory disease (maxillary sinusitis and periosteal rib lesions)?
- Do these results reflect the effect of socio-economic status rather than the effects of urbanisation? For example, in Canterbury the cemetery population from the cemetery of Sint Gregory was a combination of parishioners and inmates of St. John’s hospital for the poor and infirm (Hicks and Hicks, 2001).

1.5 Significance of the research

The countries currently known as Belgium, France and England were strongly linked economically and politically in the medieval period (Nicholas, 1992; Leguay, 2002; Clark, 2009; van Bavel, 2010). Historical research therefore regularly compares the development of the different regions (Ayton, 1994; Matthew, 1994; Goldberg, 2001; Cohn, 2004; Blair, 2005; Nicholas, 2006; Power, 2008; James, 2010; Scott, 2012; Van Steensel, 2013). This is, however, not the case for bioarchaeology. This study is the first systematic comparison of a variety of lesions representing disease in skeletons, along with demographic profiles, across these regions by one researcher for this period using a consistent methodology. Many bioarchaeological studies deal with health in a population from a single funerary context – for example, a cemetery (Grauer, 1993; Stirland, 2009; Miszkiewicz, 2012) or focus on one region or country

(Lewis et al., 1995; Lewis, 2002; Roberts and Cox, 2003; Djurić et al., 2006; Novak et al., 2012a) or look at one health indicator across a wider area on (Roberts and Buikstra, 2003) or over a longer time period (Roberts and Cox, 2003; de Beer, 2004; Holck, 2007; Cardoso and Gomes, 2009; Bernofsky, 2010). Furthermore, data may be collected by different researchers with different methodologies, thus limiting comparability. The current European module of the Global History of Health (http://global.sbs.ohio-state.edu/global.php accessed 27 January 2015) project attemps to rectify the problem by creating a database with comparable data collected using the same protocols across Europe; while bioarchaeologists in England and France are involved in this project, Belgium is currently not.

Furthermore, this research adds new skeletal data on demography and health for each region. The skeletal collections in Ghent and Caen had not been studied before, and studies involving Canterbury had focused on the priory part of the cemetery (Anderson and Andrews, 2001), the non-adult skeletons (Dawson, 2014), or only focused on one type of lesion (Miszkiewicz, 2012). This study is therefore the first to provide a more comprehensive insight into skeletal health of the adults buried in the cemetery of St. Gregory in Canterbury. It is also the first study to synthesize published and unpublished data from the Low Countries.

Lastly, respiratory disease, and periosteal rib lesions in particular, is not often studied. This is the first study to look at the frequency of respiratory disease in Belgium and France, and contributes to the limited data available for England (Chundun, 1991; Boocock et al., 1995; Lewis et al., 1995; Mays et al., 2002; Roberts, 2007; Bernofsky, 2010).

1.6 The history of bioarchaeology in Belgium, England and France

The study of human remains has developed differently in Belgium, England and France. As a consequence of the differences in development, research has a different focus and different methods are used. Even though biomolecular methods (e.g., stable isotope analysis, aDNa) are regularly used to complement macroscopic analysis (Grauer, 2012), the focus here is on macroscopic methods. A brief overview of the history of the discipline is provided for each country as well as their current status. In England the study of human remains is known under a variety of names (e.g., physical anthropology, bioarchaeology, osteology, palaeopoathology) (Roberts, 2012). In France and Belgium, on the other hand, this term does not exist and the study of human remains is often referred to as physical or biological anthropology (*l'anthropologie physique/biologique* in French, *fysische anthropologie* in Dutch).

1.6.1 France

French biological or physical anthropology developed from an interest in hominines in the 19th century (Blondiaux et al., 2012). In the early 20th century, physical anthropological studies were mostly focused on measurements of skulls in the belief that skulls presented all the "racial", physiological, psychological and pathological traits of individuals (Michel and Charlier, 2011). Throughout the 19th and 20th century there has only been a limited interest in the subdiscipline of palaepathology, with much of the research undertaken as a secondary interest by medical practitioners (Blondiaux et al., 2012). Even now, physical anthropologists tend to focus more on palaeodemography and funerary archaeology than on palaeopathology (Blondiaux et al., 2012). However, bioarchaeology courses are taught at various institutions and every institution has a different focus (Charlier, 2008). The French Palaeopathology Association (*Association de paléopathologistes de langue française* - GPLF - http://www.asso-gplf.fr/, accessed 27 January 2015) was founded in 2003 and aims to further develop palaeopathology in France. There are, however, no recording standards published for France as there are in England

1.6.2 England

England does not have many hominine fossils that were the foundation of biological anthropology in France and Belgium in the 19th century (White, 2011), and early studies focused on biometrical analyses (White, 2011; Roberts, 2012). In the second half of the 20th century, the study of archaeological human remains became strongly focused on palaeopathology by the work of Calvin Wells (1903-1976) and Don Brothwell (1933 -) (Roberts, 2012). However, the discipline has only matured in the last 30 years with the emergence of postgraduate and undergraduate courses teaching bioarchaeology in the 1980s and 1990s (Roberts, 2012). The foundation of the British Association of Bioarchaeological Anthropology (BABAO - http://www.babao.org.uk/, accessed 27 January 2015) in 1998 and the publication of recording (Brickley and McKinley, 2004) and report writing standards (Mays et al., 2004) has further developed the discipline and the quality of research in bioarchaeology in Britain as a whole (White, 2011; Roberts, 2012).

1.6.3 Belgium

Belgian physical anthropology has its foundations in biometrical studies of hominine fossils in the 19th century (Orban, 2010; Quintelier et al., 2011). From this period, Phillipe-Charles Schmerling's (1791-1836) work on hominine fossils in Wallonia is probably the best known and the study of fossils has continued in Belgium since

(Quintelier et al., 2011, Toussaint 1992). Another milestone in Belgian palaeoanthropology was the appointment of François Twiesselman as head of the anthropology and prehistory section at the Royal Belgian Institute of Natural Sciences (RBINS) in 1936 (Orban 2010). Together with Élisabeth Defrise and later André Leguebe, he worked on human variation and biometrics (Orban 2010). The study of anatomically modern past human populations only occurred sporadically in Belgium throughout the better part of the 20th century (Quintelier et al., 2011). The work by Paul Janssens was a notable exception. He produced systematic reports on human populations, including palaeopathological data (e.g. Janssens and Dequeecker, 1970). After his death in 1993, palaeopathological research more or less disappeared until the 1990s (Quintelier et al., 2011). There are no university courses dedicated to the discipline, but the basic principles of the study of human remains are taught at the *Université Libre de Bruxelles (ULB)* and the *Université de Liège* (ULg) (Quintelier et al., 2011). Most researchers working in the field have gained their training abroad (Quintelier et al., 2011). There is no Belgian association for physical anthropology, but Flemish bioarchaeologists are connected through the Dutch association (*Nederlandse Vereniging voor Fysische Anthropologie* – NVFA - http://www.nvfa.nl/, accessed 27 January 2015). Studies that are undertaken do not follow national guidelines, but are an amalgamation of guidelines written in other countries (Quintelier et al., 2011).

1.7 Definitions

This section aims to define some of the terms and concepts that have been used in this research. First, as this project looks at urban health, definitions of what urban is, are considered, and then some of the geographical terms in the project are clarified. This is followed by definitions of health, stress and adaptation.

1.7.1 Urban

What is “urban” is easy to recognise but hard to define, both in a modern and archaeological context Vlahov and Galea (2002) considered how 228 countries defined “urban” in data held by the United Nations. They found quite a variety of factors were used, including administrative, population size and density, and functional characteristics. The administrative definition was by far the most popular as it was used by approximately half of the countries studied (Vlahov and Galea, 2002). However, researchers have since argued that a simple urban-rural dichotomy does not accurately reflect the complexity of settlements today and some studies are therefore advocating the use of a continuous scale from rural to urban based on scoring different aspects of the environment, including population size and density, access to services (eg. healthcare), economic activity, transport links, etc. (McDade and Adair, 2001; Dahly and Adair, 2007; Novak et al., 2012b; Cyril et al., 2013).

Administration, population size and density, and functional characteristics are also the main factors used in defining “urban” in late medieval settlements (Ottaway, 1992; Schofield and Vince, 2005; Giles and Dyer, 2007). Historians have used contemporary charters and privileges to define towns and cities based on administration (Anderson, 2011). However, not all towns in England received borough status (Sweetingburgh, 2010a). The lower limit of the population size used for defining urban settlements in late medieval Europe has varied between 1000 and 10,000 inhabitants, which has significant ramifications for further interpretation (Allen, 2000; Giles and Dyer, 2007). Population size estimates are based on records related to taxation (Leguay, 2002a; Sweetingburgh, 2010a). The number of households paying a “hearth” tax (a tax every household had to pay) is multiplied by an estimation of the number of people per household. Small differences in educated guesses about the size of a household can therefore lead to vastly different estimates. Furthermore, the poor and the clergy may have been exempt from paying this tax and may therefore not have been included in the population estimate (Leguay, 2002a). Population size and density are therefore not reliable indicators of urbanisation in past populations. Occupational diversity is therefore often seen as the critical feature for determining urbanisation (Sweetingburgh, 2010a).

As historical documents are often not available for archaeological settlements, archaeologists have been more open-minded about defining “urban” in past populations (Anderson, 2011). In 1976 Biddle provided a list of potential attributes of an urban centre (see Table 1.1). He argued that at least three or four attributes should be present to define a settlement as urban (Biddle, 1976). Since then, other definitions have been suggested and the focus has been increasingly on function instead of population size. First, the economy should be diverse and not dominated by agriculture (Reynolds, 1992; Palliser, 2000a; Blockmans and Hoppenbrouwers, 2007; Giles and Dyer, 2007). An urban settlement therefore depends at least partially on its hinterland for its food supply and other resources (Beresford, 1967; Palliser, 2000a). However, not all urban settlements would have been equal. In medieval England there was a clear hierarchy in urban settlements: London was in a class apart, and then there was a tier of large towns which included among others Canterbury, Norwich, and York followed by smaller towns (Anderson, 2011). In Flanders, Ghent was one of the “three cities” and one of the largest towns in the region (Nicholas, 1992). Lastly Caen was only second to Rouen within Normandy with many smaller towns nearby (Neveux, 1997).

Table 1.1: Applying Biddle's (1976:100) defining factors of an urban centre to Caen, Canterbury and Ghent

Factor	Caen	Canterbury	Ghent
'urban'-type housing and plots	√	√	√
a role as a central place	√	√	√
a relatively large and dense population	√	√	√
social differentiation	√	√	√
a planned street system	√	√	√
legal autonomy	√	√	√
a diversified economic base	√	√	√
complex religious organisation	√	√	√

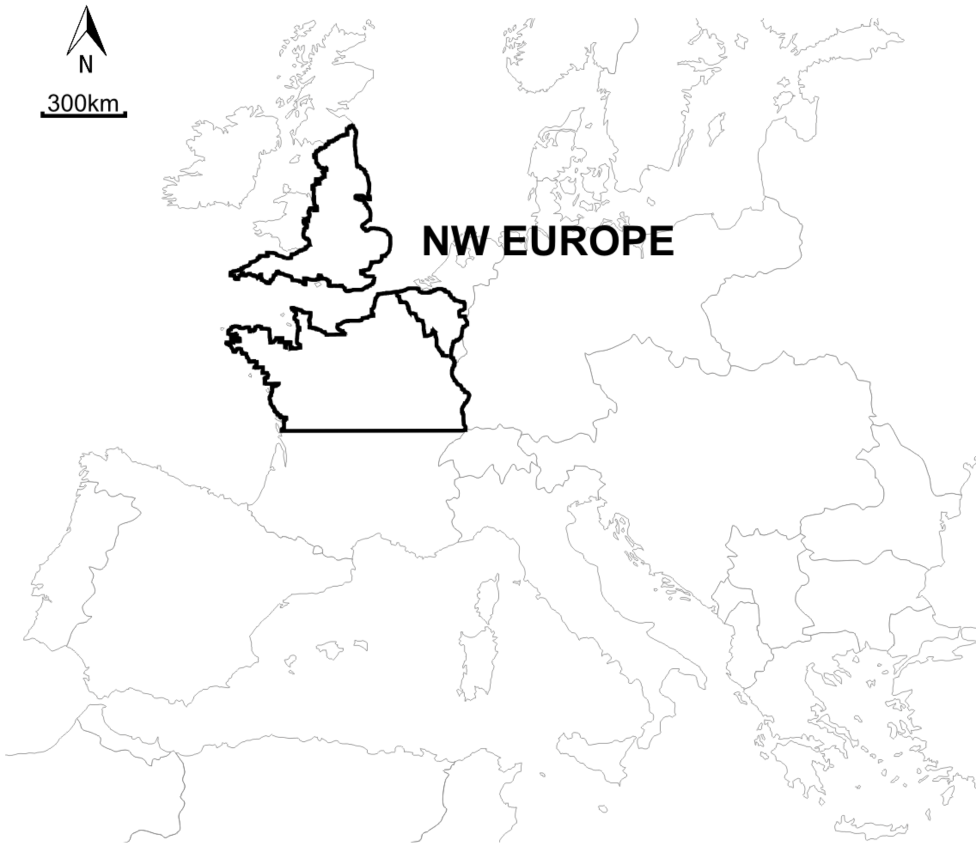
Table 1.1 shows that Caen, Canterbury and Ghent can all be considered urban centres in the Late Medieval Period. All three settlements had a relatively large and dense population; have a strong influence over their hinterland, and had a diverse economy which was not based on agriculture a(Désert, 1981; Nicholas, 1987; Royer-Hemet, 2010). Each town will be explored in more detail in Chapters 3 and 4.

1.7.2 Geographical terms used in this research

(i) ***North-West Europe***

For the purpose of this thesis NW Europe is defined as England, Belgium and northern France (see Figure 1.2).

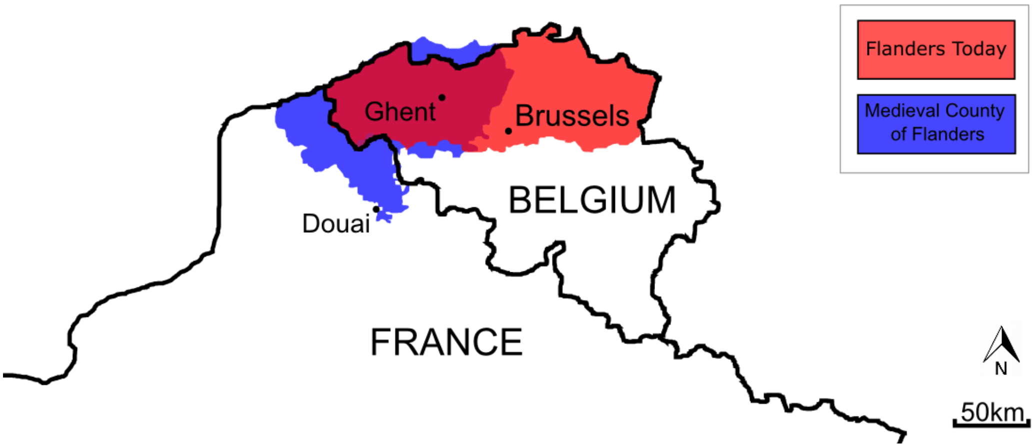
Figure 1.2: NW Europe as defined in this project



(ii) ***Flanders***

Flanders currently describes the Dutch-speaking region of Belgium. Figure 1.3 shows the medieval County of Flanders, which covered a significantly different area. In this thesis, the term Flanders will most commonly be used to refer to the medieval county.

Figure 1.3: A comparison of the geographical shape of the medieval County of Flanders with the shape of Flanders within Belgium today



1.7.3 Late Medieval

The "Middle Ages" is almost universally used in Europe to demarcate the millennium between the fall of the Western Roman Empire and the Renaissance (Palliser, 2000a). This project has focused on the Late Medieval Period (12th – 16th century).

It is worth noting here that the use of the cemeteries in Ghent and Caen extend beyond the 16th century and up to the 18th century. It is therefore possible that skeletons from the early modern period (16th – 18th century) are included in this research. For the purposes of comparison, the focus in comparing these sites is the Late Medieval Period. The dating of the sites is explored further in chapter 4.

1.7.4 Health

The WHO defines "health" as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 1946). It is, however, not possible to accurately interpret mental and social well-being in past populations (Reitsema and McIlvaine, 2014). Furthermore, inferring physical health is not straight forward (Wood et al., 1992). Not all human diseases leave signs in the skeleton (e.g., mental disease, diabetes, heart disease) (Sodjinou et al., 2008; Riva et al., 2009). In addition, some diseases only lead to bone lesions in a small percentage of people (e.g. tuberculosis - Pigrau-Serrallach and Rodríguez-Pardo, 2013). Moreover, there are only a limited number of ways in which the bone can respond to disease: either by additional bone growth, or by destruction of the bone or dental tissues already present. Very few lesions are therefore pathognomonic (specific to a particular disease process), i.e. cannot be associated with a specific disease. In addition, it takes time for lesions to develop. Therefore, an illness which kills quickly (for example, the plague) will leave no trace. As a consequence skeletons with lesions, which are usually characteristically chronic and healed, may actually be healthier than those without lesions (Wood et al., 1992). The complexity of interpreting skeletal lesions is often referred to as the “osteological paradox”, as defined by Wood et al. (1992). The use of the term “health” in this thesis therefore reflects the skeletal health of the skeletons studied included in this research. This is, however, complemented with data from other sources of information available to improve the interpretation of the frequency rates found in the skeletal remains studied.

1.7.5 Stress and adaptation in bioarchaeology

One way that quality in human health has been interpreted in bioarchaeology is through the presence of “stress indicators”. The “stress” concept has been around in medicine since the 19th century. It became more popular as a result of Hans Seyle’s work throughout the 20th century on the General Adaptation Syndrome (G.A.S) (Selye, 1976; Jackson, 2013). The G.A.S. is defined as the non-specific reaction of the body to internal or external demands. The underlying assumption is that the body has a normal level of resistance which it aims to maintain homeostasis (Selye, 1976). When a demand is made on the body, there will be an initial alarm response (phase I). When the demand continues, the body will try to resist (phase II) and return to homeostasis through adaption to the demand from the stressor. Failure to adapt will lead to exhaustion and death (phase III) (Selye, 1976).

A person is constantly bombarded by multiple stressors. Koolhaas et al. (2011) argue that there is an ideal environmental range for every living creature within which no adaptation is necessary. It is possible to adapt to conditions outside this range, but resistance to other stressors will be reduced. In addition, they argue that the stress response is not always the same, and control, predictability and experience will reduce the stress response. Essentially, every person is an individual who will respond to stress in different ways.

Stress cannot directly be observed in the skeleton, but some adaptations in phase II of the G.A.S. will lead to observable skeletal lesions (Klaus, 2014; Temple and Goodman, 2014). For example, dental enamel defects are the result of interrupted growth of the dental enamel due to disease or dietary deficiency in childhood as energy is diverted to other parts of the body to enable the survival of the person (Aufderheide and Rodríguez-Martín, 1998). Goodman et al. (Goodman et al., 1984, 1988) identified a series of skeletal indicators that could be used to identify stress from the skeleton (See Chapter 2 for details). However, the link between health and skeletal lesions is not that straightforward (see section 1.7.4) and therefore no direct link between “stress” and skeletal lesions has been identified (Tanner and TAPS Bolivia Study Team, 2014). Skeletons without lesions are therefore a combination of those who were not subject to stress and those who died from it very quickly (Wood et al., 1992). Furthermore, levels of disease risk are not uniform in a population (Wood et al., 1992; Reitsema and McIlvaine, 2014; Tanner and TAPS Bolivia Study Team, 2014; Wilson, 2014). Disease risks depends on a variety of factors, including biological and immunological variation as well as differences in sanitation and nutrition (Wood et al., 1992; Tanner and TAPS Bolivia Study Team, 2014). Lastly, the aetiology of some of these lesions may not be related to stress (Wood et al., 1992; Lewis and Roberts, 1997).

This thesis uses the term “stress” to refer to factors that have a negative impact on health of the population. The term “indicator of adaptation” is then used to refer to the skeletal and dental lesions that are interpreted as reflecting stress.

1.8 Thesis structure

This thesis is organised in six further chapters:

- Chapter 2 reviews current evidence of the effect of the urban environment on health. It identifies the challenges that are faced by rapidly developing urban populations today. It also includes a discussion of previously published research in bioarchaeology with a special focus on urban health.
- Chapter 3 applies the challenges identified for modern populations in Chapter 2 to Late Medieval urban populations using archaeological and historical data. It focuses on Caen, Canterbury and Ghent, but as limited data is available for these towns, it draws on data from across Europe.
- Chapter 4 describes in detail the sites that have been used in this study, the data that was gathered for each site and the analyses undertaken.
- Chapter 5 provides the results from the analyses in Chapter 4 for each town individually before comparing the results from the three towns.
- Chapter 6 discusses the results provided in Chapter 5. First, it discusses the results within each region, drawing on additional sources of information discussed in Chapter 3. It also includes the data available from other sites. It then brings the results from the three towns together to interpret regional differences and similarities.
- Lastly, Chapter 7 summarises the research, discusses its limitations, and provides suggestions for future work

Chapter 2 Adaptation to environmental impacts: Clinical and bioarchaeological evidence for poor urban health

2.1 Introduction

The aim of this thesis is to compare health in late medieval towns. In order to understand the factors that may have impacted on human health in the past, this chapter first reviews the factors that impact on human health in an urban environment today. Chapter 3 then draws on archaeological and historical evidence from late medieval Caen, Canterbury and Ghent to explore how these factors would have affected these towns in particular. As these towns grew exponentially between the 9th and 13th centuries AD (Nicholas, 1987; Neveux, 1997; Mate, 2010a), modern examples are drawn from the rapidly developing towns and cities in developing countries in favour of the established and slowly growing towns and cities in the developed world (Novak et al., 2012b; Cyril et al., 2013).

The second half of this chapter aims to relate the themes identified in modern populations to identifiable skeletal indicators. It therefore reviews previous bioarchaeological research on health in past populations, with a special focus on urban health. The methods used to record the skeletal indicators that have been retained for this research are described in further detail in Chapter 4.

2.2 Clinical evidence for poor urban health

In the developed world, living in an urban environment is currently considered beneficial to health (Riva et al., 2009). This ‘urban advantage’ only developed in the 20th century and is the result of investment in infrastructure to supply inhabitants with adequate potable water, as well as deal with waste effectively benefits (Cyril et al., 2013). Furthermore, there are strict regulations to maintain these good sanitary conditions benefits (Rydin et al., 2012). In developing countries, the infrastructure is often strained as a consequence of exponential growth leading to sub-optimal living conditions (Dahly and Adair, 2007). The following themes which can influence human health are discussed:

- **Socio-economic status:** even in the developed world, differences in health can be identified between the rich and poor in urban areas (e.g., Ferrer and Palmer, 2004; Levin and Leyland, 2006)
- **Housing:** the quality of the house and the population density within a residence (crowding) affect human health (e.g. Braubach et al., 2011).

- **Waste management**: inadequate waste management leads to increased contamination and an increased prevalence of certain diseases (e.g. Karn and Harada, 2002)
- **Water management**: water can carry disease pathogens, especially in combination with poor waste management (e.g. WHO, 2011)
- **Availability and access to food:** the urban economy is not focused on agricultural production and food therefore needs to be imported from the countryside or other towns (e.g., Hatløy et al., 2000). Moreover, in many areas around the world some food is produced within cities (e.g. Simatele and Binns, 2008)
- **Migration:** migrants may carry disease pathogens and are therefore an important factor in the spread of disease (e.g. Funk et al., 2010)

It is important to stress here that these themes are not only applicable to the urban environment. However, the increased pressure on resources and infrastructure in towns and cities due to an increased population size and density may exacerbate the problems faced by urban communities in comparison to rural ones (Bettencourt and West, 2010; Cyril et al., 2013).

2.2.1 Socio-economic status

Towns and cities provide opportunities that cannot be found in rural contexts, and many poor people are attracted by these opportunities (McDade and Adair, 2001). For example, in a study of children in 47 countries Van de Poel et al (2007) found that the difference in health between the rural rich and the urban rich was small. On the other hand, urban poor children had worse health than those from rural areas (Van de Poel et al., 2007). Monetary payment is a lot more important in urban areas than in rural contexts, and inequality in income is also greater in urban populations (Van de Poel et al., 2007). The poor will be living in the poorest quality housing with least access to good quality food, clean water and public services (Alirol et al., 2011; Brender et al., 2011). Socio-economic status is therefore discussed throughout this chapter.

2.2.2 Outdoor air quality

Air pollution in urban settlements is the result of a complex mixture of natural and human-made sources. The former include topography, geography, and weather. For example, Los Angeles lies in a valley with little air movement. Pollutants therefore have a tendency to "hang over" the city (Hertel and Goodsite, 2009). On the other hand, wind and rain can disperse the pollutants over a wider area and thus dilute them (Hertel and Goodsite, 2009; Salmond and McKendry, 2009). Wildfires and volcanoes can also lead to air pollution (Longo et al., 2010; Finlay et al., 2012).

The most important factors of human-produced sources of air pollution in the developed world are currently car emissions and industry (Bloss, 2009; Vardoulakis, 2009). However, in the developing world, the burning of wood and charcoal as a primary fuel is a strong contributory factor (Bloss, 2009; Maynard, 2009; Brauer et al., 2012). Brauer et al (2012) have shown that air pollution in South America reduced between 1990 and 2005 as a result of the reduced reliance on fossil fuels. The incomplete burning of these biomass fuels leads to respiratory disease (Desai et al., 2011). An estimated one percent of all respiratory infections can be attributed to outdoor air pollution alone (Prüss-Üstün, 2006).

Studies in Kenya and Ethiopia in Africa have shown that the emergence of towns has a negative impact on the respiratory health of their inhabitants (Yemaneberhan et al., 1997; Ng'ang'a et al., 1998). However, urban centres are diverse and the presence of greenery and the proximity of buildings affect levels of pollution (Bloss, 2009; Vardoulakis, 2009). Streets lined with high buildings on either side create a "canyon"-effect, which has increased concentrations of pollution. Parks and open spaces, on the other hand, lead to lower concentrations of pollution. Furthermore, industry plants and construction sites can create localised pollution hotspots within a settlement (Vardoulakis, 2009).

2.2.3 Housing

In the previous section, the use of biomass fuels was given as a cause for air pollution (Brauer et al., 2012). These fuels would also have been used within the house for heating and cooking and thus lead to indoor air pollution (Kim et al., 2011). The factors affecting indoor air pollution and their impact on health are explored here in detail.

Air quality is not the only factor affecting human health indoors. As people live closer together, communicable diseases can spread easier (Prüss-Üstün, 2006). Crowding is defined here as well as its effects on human health. The importance of effective waste removal and the need for potable water are discussed below.

(i) ***Indoor air quality***

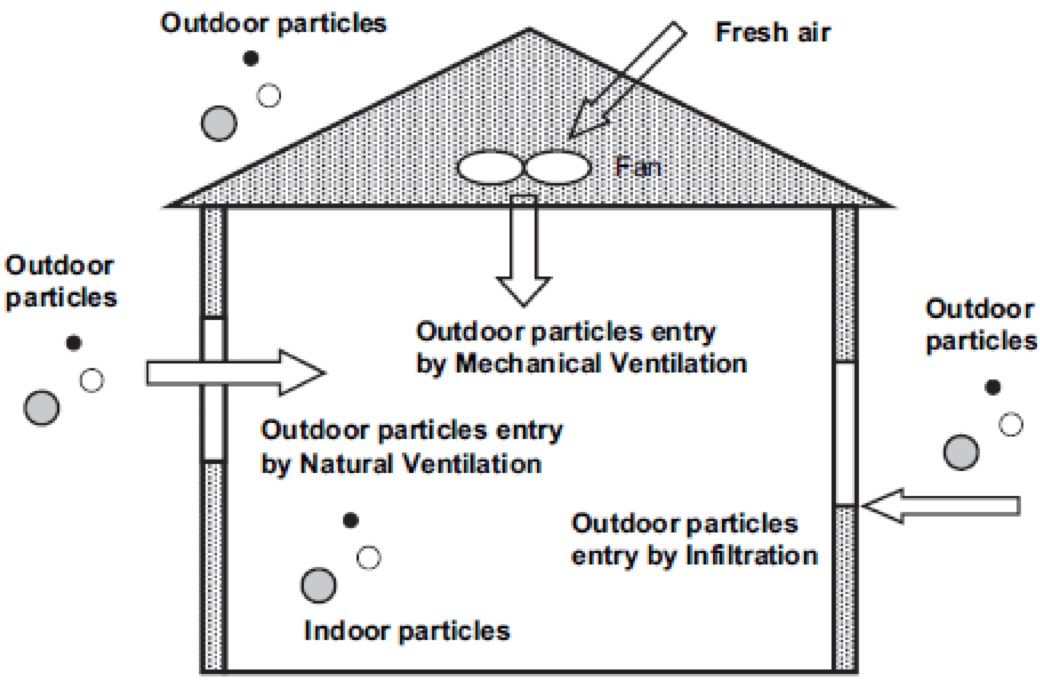
People in the developed world currently spend on average 90% of their time indoors, and this even more for some vulnerable groups in society (Ormandy and Braubach, 2011). Women and children in many developing countries have been found to be most affected by indoor air pollution as they spend more time indoors (Bruce et al., 2002; Ekici et al., 2005; Hertel and Goodsite, 2009).

Indoor air pollution has a variety of sources (Vardoulakis, 2009):

- ambient outdoor air,
- burning of biomass fuels,
- biological pollutants such as mould, bacteria and viruses, and dust mites.

The interaction between indoor and outdoor air depends on levels of ventilation and infiltration (see Figure 2.1). Opening doors and windows (ventilation) will lead to exchange of indoor and outdoor air and its particulates (Chen and Zhao, 2011). Even when windows and doors are closed, indoor and outdoor air are exchanged through small openings within walls, roofs and floors. This is called infiltration (Chen and Zhao, 2011). The indoor air quality will therefore depend on the outside air quality (Vardoulakis, 2009; Chen and Zhao, 2011) and this is discussed elsewhere.

Figure 2.1: The different ways in which the indoor air is influenced by outdoor air (Chen and Zhao 2011: 276)



Biomass fuels (wood, animal dung, crop residues and coal) are used by approximately a third of the world's population for domestic energy needs (Kim et al., 2011). However, as much as 36% of lower respiratory infections worldwide may be linked to the use of these fuels (Prüss-Üstün, 2006). Moreover, Hertel and Goodsite

(2009) estimated that their use in the household accounted for 1.6 million deaths in 2000. In a study of unpolluted rural Turkey, Ekici (2005) found that 23% of the cases of chronic respiratory disease were linked to exposure to combustion of biomass fuels.

Indoor dampness and mould are one of the most important indoor problems around the world as particulates of biological origin (bioaerosols) have been found in elevated concentration in affected buildings (Jaakkola et al., 2011). In cold climates dampness has been estimated to affect 5 - 30% of the population, with 5 - 10% affected by mould. In moderate and warm climates the prevalence of dampness varies between 10% and 60% of mould between 10% and 30% (Quansah et al., 2012).

(ii) ***Crowding***

Crowding refers to a state in a household where the number of residents exceeds the capacity of the dwelling regarding shelter, facilities and space (Baker et al., 2011b). The definition of crowding is, however, largely subjective and there is no consensus yet (Zhang and Chen, 2014). Some studies use number of people per room, while others look at a minimum surface area per person (Baker et al., 2011b; Zhang and Chen, 2014). Cultural factors and context need to be taken into account as the perception of crowding varies between cultures (Baker et al., 2011b). Contextual factors include: the age, sex and relationship of household members (Baker et al., 2011b). In the UK the ‘room standard’ means that a dwelling is overcrowded if people over the age of 10 are required to share a room for sleeping purposes with someone of the opposite sex, unless they are living as husband and wife. However, the rooms do not have to be bedrooms, but rooms with other purposes (e.g. living room) can also count towards the calculation of crowding (Edgar and Meert, 2005).

High levels of crowding are associated with increased levels of infectious diseases that are transmitted between humans as there is an increased risk of prolonged exposure (Prüss-Üstün, 2006). This has been shown for respiratory infections (e.g. tuberculosis, pneumonia, bronchiolitis,…) and infections transmitted through direct contact (e.g. hepatitis B) (Prüss-Üstün, 2006; Baker et al., 2011b). Furthermore, crowding is an important factor in the transmission of influenza as it has been estimated that 48% of transmission occurs between family members and household members (Baker et al., 2011b). Although crowding is directly linked with larger settlements, it is also very strongly linked to poverty, as poor people are less likely to be able to afford the cost of space (Solari and Mare, 2012). In addition, migrants are more likely to live in overcrowded conditions (Zhang and Chen, 2014).

2.2.4 Waste management

In many areas of the world urbanisation has outpaced the development of infrastructure to deal with waste and waste water. When waste collection services do not work adequately, piles of waste emerge in the streets and on empty lots (Alirol et al., 2011). This leads to soil, air and water pollution. For example, in Teresina, Brazil infection with visceral leishmaniasis is six times higher in areas of the city where there is no regular rubbish collection (Alirol et al., 2011). Furthermore, the accumulation of waste attracts rodents, which may be carrying disease pathogens (Alirol et al., 2011). For example, in Mahajanga (Madagascar), where plague is endemic, the epicentre of outbreaks is a densely populated area which generates the town's largest quantity of waste (Alirol et al., 2011). Respiratory diseases associated with air pollution have already been discussed above and water related diseases are discussed in more detail below.

In West African cities less than 10% of waste water undergoes primary or secondary treatment (Qadir et al., 2010) and in the slums of Mumbai City in India open sewers run between the houses and discharge in nearby land, roadside drains or waterways without treatment (Karn and Harada, 2002). Furthermore, in many areas untreated water is used for fertilisation on urban and peri-urban farms (Simatele and Binns, 2008; Qadir et al., 2010; Battersby and Marshak, 2013). Treatment is even resisted by farmers as it removes nutrients and thus affects the growth of crops (Qadir et al., 2010). However, this ignores the potential impact on health. Waste water from industrial use may contain elevated levels of metals, metalloids, and volatile or semi-volatile compounds, which can be absorbed by crops when used for watering (Qadir et al., 2010). Domestic waste water on the other hand is more likely to contain pathogens. In Zambia the use of domestic waste water has been linked to outbreaks of cholera and dysentery (Simatele and Binns, 2008; Battersby and Marshak, 2013).

Problems with waste management are not limited to the developing world. In part of the Campania region in Italy, a study of waste disposal centres showed that authorities could not keep up with the waste produced by the population. Furthermore, the region had also been used for illegal waste dumping by the eco-mafia. As a result, agricultural land could not be used safely (Senior and Mazza, 2004; D'Alisa et al., 2010).

2.2.5 Water management

Water management involves the provision of clean water for consumption and domestic use (WHO, 2011), but also the disposal of waste water (see above).

Estimates have suggested that 7.5 litres of safe water are needed per day per person for drinking, food preparation and personal hygiene. This rises to 50 litres per day when personal hygiene, food hygiene, domestic cleaning, and laundry needs are taken into account (Hunter et al., 2010). Of the global population today, 89% of people now have access to improved water sources (piped water, protected wells and standpipes) (Hunter et al., 2010; UNICEF and WHO, 2013). In the global urban population only 4% has no access to improved water sources. However, this number is misleading as in some areas the water supply is intermittent and insufficient for daily needs. For example, in Mumbai city slums most people acquire water through communal taps (Karn and Harada, 2002). However, there may only be water in communal taps for four hours a day (Karn and Harada, 2002). This limit in availability increases the chance of contamination (UNICEF and WHO, 2013). Even when clean water is available, improper storage may lead to contamination (Wright et al., 2004; WHO, 2011). Water can cause human disease in a variety of ways. Micro-organisms and chemicals in water that is consumed can lead to disease. For example, cholera is caused by the bacterium *Vibrio cholera* and the poisonous arsenic naturally occurs in ground water in some areas of the world (WHO, 2011; Flanagan et al., 2012). Some of these organisms may only spend part of their lifecycle in water and lead to parasitic infections (e.g. waterborne transmission of protozoan parasites) (WHO, 2011). Furthermore, standing water can provide a breeding ground for water-related animals carrying pathogens. For example, mosquitos carrying diseases like malaria or dengue fever (WHO, 2011).

Extreme weather or overarching climate (e.g. flooding) can have a strong negative impact on the quality of the water. In the case of flooding, the water may recede quickly, but any damage to previously existing systems of water and waste management may have a longer-term impact on the quality of the water (WHO, 2011). For example, in the slums of El Salvador open-drainage gutters tend to overflow in the rainy season, flooding streets and adjacent homes. As a result, rats carrying *Leptospira interrogans* proliferate, this leads to outbreaks of leptospirosis (Alirol et al., 2011).

2.2.6 Availability and accessibility of food

Diet and nutrition are important factors of human health because malnutrition not only leads to nutritional deficiencies such as anaemia, but also compromises the immune system and thus increases the risk of adverse health outcomes in other illnesses (Prüss-Üstün, 2006). Studies in developing countries have consistently found that a wider variety of foodstuffs and food groups are consumed in urban centres compared to rural areas (Hatløy et al., 2000; Van de Poel et al., 2007; Ruel et al., 2010). There is, however, a strong correlation with socio-economic status. The diversity of foodstuffs consumed by the urban poor is comparable to diversity in rural areas. The diversity of foodstuffs increased with available income (Ruel et al., 2010). This is the result of the need for monetary payment in urban areas as sufficient income is required to buy the food available (Van de Poel et al., 2007). In urban centres around the world over 90% of the inhabitants are net buyers of food. In rural areas more food is produced and the proportion of net buyers in developing countries vary between 29% in Mozambique and 58% in Peru (Ruel et al., 2010).

One way to off-set this issue is urban farming. In Western countries the growing of food within a town or city is usually limited to allotments and community gardens which focus on the benefits of social cohesion and community (Battersby and Marshak, 2013). In other parts of the world "urban agriculture" (growing crops as well as raising livestock) is much more common and can be an important source of food and income for everybody (Bryld, 2003; Simatele and Binns, 2008; Battersby and Marshak, 2013). There are, however, health concerns related to urban agriculture and especially to raising of livestock in close proximity to humans (Battersby and Marshak, 2013). First, when compost heaps are not managed correctly, the waste gases released are adverse to human health and lead to an increase in disease (for example, bronchitis, tuberculosis, and cancer) (Bryld, 2003). For example, the use of sewage has been associated with outbreaks of cholera and dysentery in Zambia (Simatele and Binns, 2008; Battersby and Marshak, 2013). Furthermore, standing water on urban farms has been considered a breeding ground for mosquitos. As malaria is endemic in Zambia, this is a major health concern (Simatele and Binns, 2008). Less visible, urban farming also results in complaints about the odour and noise (Battersby and Marshak, 2013).

2.2.7 Health care and education

Urban health care tends to be better than rural care as a result of higher demand and higher investment (Heckman et al., 1998; McDade and Adair, 2001; Harttgen and Misselhorn, 2006; Balarajan et al., 2011). This is not to say that there is no quality care in rural areas. However, McDade and Adair (2001) found that the provision of health care in urban areas was more consistently of a high standard, while rural health care provisions tended to be more transient. Even in Canada, a country with a universal health care system, differences in care and health outcomes can still be observed between urban and rural populations (Gamble et al., 2011). However, health care can be expensive and the poor may therefore not be able to afford the care available (Van de Poel et al., 2007; Balarajan et al., 2011).

Opportunities for education are also better in towns. As towns grow, educational and research institutions tend to grow 15% more rapidly than can be expected (McDade and Adair, 2001; Bettencourt and West, 2010). A lack of education is associated with adult socio-economic status and an earlier age at death across a variety of settlement types in developed as well as developing countries (Baker et al., 2011a). Education can also be related to housing conditions. A study of 25,864 individuals in eastern Germany showed that level of education was strongly correlated with the chance of living in damp housing. Those with poorly educated parents were 4.8 times more likely to live in damp housing than those with highly educated parents (WHO, 2009).

Despite these general trends for better access in health care and education in urban settlement types, it should be highlighted that there is a great heterogeneity regarding basic infrastructure, health services and education across rural and urban settlement types around the world today (McDade and Adair, 2001). Even when those services are available, they may only be limited to the people who can afford them; this is because high prices and a lack of health care may make them inaccessible for the poor (Van de Poel et al., 2007).

2.2.8 Migration

Migration from rural areas or other urban centres is a substantial factor in the growth of cities (Alirol et al., 2011). This migration takes place for a variety of reasons, can be temporary or permanent, and over short or long distances. The general direction of migration is from rural to urban environments or from other urban to urban contexts (Funk et al., 2010; Baker et al., 2011b). For example, 40% of China's urban migrants come from a rural environment (Gong et al., 2012). The long distance travel that is common today can lead to rapid spread of infectious diseases. Recent examples are avian influenza (H1N1), and SARS (severe acute respiratory syndrome) (Alirol et al., 2011).

One of the problems with rural to urban migration is that pathogens which are normally associated with rural environments can be introduced into the urban environment (Baker et al., 2011b). Sometimes this means the emergence of new diseases in urban areas. Several rural pathogens have also adapted to urban environments (Alirol et al., 2011). On the other hand, moving to an urban area exposes migrants to pathogens associated with high population density environments (for example tuberculosis) and are more likely to suffer more severe infections due to lack of immunity compared to the local population (Alirol et al., 2011), while the indigenous urban population may have become immune to those pathogens. For example, in Kabul, Afghanistan the local population has been noted to become infected and immune to cutaneous leishmaniasis in childhood, but there is high transmission of this disease between newcomers (Alirol et al., 2011). Nevertheless, urbanisation does not always have a negative impact on the spread of infectious disease. Several diseases have reduced prevalence rates in urban areas. For example, malaria is endemic in sub-Saharan Africa, but its prevalence in urban areas is much lower than in rural areas (Alirol et al., 2011).

Sometimes migration is reversed (urban to rural) and people may move when job prospects improve or when they fall ill (Dyson, 2003). This reverse migration contributes to the spread of disease into rural regions (Dyson, 2003; Funk et al., 2010). For example, when an infectious disease appears people may flee to avoid infection (Funk et al., 2010), as seen in a presumed outbreak of the bubonic plague in Surat (India) in 1995 where hundreds of thousands of people fled (Funk et al., 2010).

2.2.9 Summary

So far this chapter has discussed the challenges faced by rapidly growing urban populations today. It has shown that the urban growth can have a negative impact on the health of the inhabitants. Infrastructure can often not keep up with the growth. However, contamination of the water supply and inadequate waste management can lead to an increase in disease transmission. Indoor and outdoor air pollution result in higher levels of respiratory disease. Moreover, high population density and the high mobility of people in urban centres can lead to higher transmissions of communicable diseases. Lastly, all these factors tend to affect the poorest of the population most. The second half of this chapter aims to translate these issues to indicators that can be identified in human skeletons from archaeological populations and therefore be used to address the hypotheses of this research.

2.3 Bioarchaeological evidence of urban health

The remainder of this chapter reviews previous research on the health of past populations from skeletal collections, with a special focus on differences between urban populations. Firstly, indicators that have previously been used to interpret poor health will be discussed. Then potential indicators of respiratory disease will be discussed and their use as proxies for poor air quality will be explored. Lastly, previous research on dental disease will be discussed as dental disease may lead to maxillary sinusitis (see below).

2.3.1 Indicators of adaptation

This section will focus on previous research on interpreting stress from skeletal indicators. The definitions of stress and adaptation were discussed in the previous chapter. Stress is the non-specific reaction to stimuli (Selye, 1976b) and the presence of indicators in skeletal remains indicate that a person has adapted to those stimuli, i.e. they survived the “insult” (Temple and Goodman, 2014). In bioarchaeology these indicators include skeletal evidence of disrupted growth of bones and teeth due to nutritional deficiencies and disease. The indicators have therefore been used to interpret health, sanitary conditions and social status in past populations. As shown in Chapter 1, health is not linearly associated with skeletal indicators. The interpretation of skeletal lesions therefore requires additional sources of information to interpret prevalence rates. This background information is discussed in Chapter 3. The first part of this chapter has shown that poor sanitary conditions and poverty can lead to nutritional deficiencies and worse health. Some studies in archaeological populations have been able to differentiate between social groups (e.g. Angel, 1984; Cohen, 1989), but other studies have been less successful (e.g. Wilkinson and Norelli, 1981; White et al., 1993). In a socially stratified society, different social strata may be equally affected by a stressor (e.g., famine) and skeletal indicators, on their own, are therefore insufficient to interpret social status from skeletal remains (Robb et al., 2001). Nevertheless, the potential impact of socio-economic status on the prevalence of these lesions is considered within the wider context (see Chapter 3).

A list of potential indicators of stress in skeletal remains (see Table 2.1) by Goodman and co-workers (1988) has been the basis of much research on stress bioarchaeology. The problems with some of these “stress markers” will be discussed here, rationalising why some indicators have been removed. The indicators that have been retained for this study will then be discussed in more detail below.

Table 2.1: Potential stress indicators identified by Goodman et al (1988: 179) showing those used in this research

Not used in this research	Used in this research
Dental asymmetry	Adult stature
Dental crowding	Enamel hypoplasia
Growth curves/ retardation/ shape differences	Periosteal infections
Harris lines	Cribra orbitalia
Life tables and mortality schedules	
Osteoporosis	
Porotic hyperostosis (vault lesions only)	
Sexual dimorphism	
Skull base height	
Traumatic lesions	
Vertebral canal stenosis	

The first problem is that the aetiology of many of these indicators is poorly understood (Lewis and Roberts, 1997) and stress may not be a dominant factor. For example, some of these indicators may have a strong genetic component (Goodman et al., 1988). These include: sexual dimorphism, vertebral canal stenosis, skull base height, dental asymmetry, and dental crowding (Goodman et al., 1988), and it is not possible to distinguish the genetic from the stress components.

The limitations of bioarchaeological methods (see Chapter 1 and Chapter 6) also affect stress research in this study. For example, methods for estimating the adult age-at-death do not provide accurate age ranges (see Chapter 4 for details) and ages are therefore commonly categorised into broad age ranges: young adult, middle adult, and old adult (Buikstra and Ubelaker, 1994; O'Connell, 2004). As a result, subtle differences in age-at-death will not be picked up. In this study age-at-death has been recorded for all skeletons when possible. However, no life tables or mortality schedules were created.

Furthermore, Harris lines and traumatic lesions were not recorded in this study as they require radiography for detailed study; it was not possible to radiograph bones in this study. Another limitation is that some indicators can only be inferred from a subset of the population. For example, growth curves can only be created based on data from non-adult skeletal populations and can therefore not be applied in this study that focuses on adult remains. Osteoporosis, on the other hand, is more common in post-menopausal women, which would only be relevant to a small proportion of the skeletons analysed in thus study. Furthermore, it would require digital imaging for accurate recording (Curate, 2014), which was not available.

On the basis of the discussion above, the following indicators were retained, and are discussed in more detail below:

- **Dental enamel hypoplasia**: a disruption to the growth of the dental enamel as nutritional sources are diverted away from their growth for the survival of the person (Aufderheide and Rodríguez-Martín, 1998).
- **Cribra orbitalia**: a sign of nutritional stress during the growth period (Walker et al., 2009).
- **Adult stature:** it has a strong genetic component (Silventoinen et al., 2003; Lettre, 2011), but it has been shown that reduced stature can be associated with environmental factors (Allen, 1994; Ulijaszek, 1994; Black et al., 2008).
- **Non-specific periosteal reaction:** a reaction to disrupted normal physiology of the periosteum (Klaus, 2014) .

(i) ***Indicators used in this research***

Dental enamel hypoplasia (DEH)

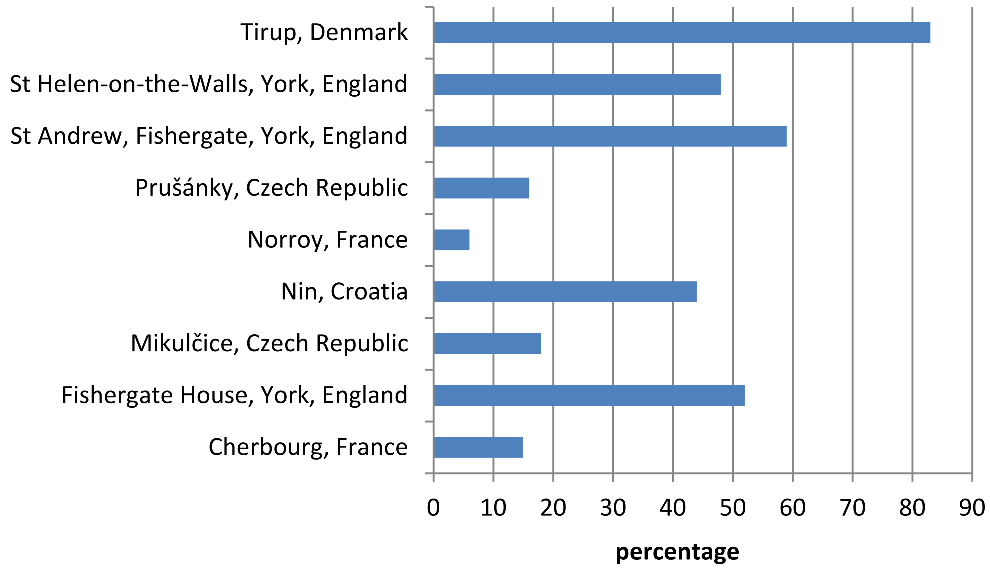
Dental enamel hypoplasias are defects which appear during the formation of the dental crowns of the mandible or maxilla. Dental enamel develops in two stages (Hillson, 2005). In the first stage a layer of ameloblastic cells containing both organic and inorganic components are deposited on the exterior surface of the crown dentine (Hillson, 1996). In the second stage these cells mature. The organic deposits are broken down and the mineral and crystallite components remain on the crown's surface as enamel (Hillson, 1996). Enamel defects occur when the first stage is disrupted by "stress" as nutrients are diverted from tooth formation to other biological systems essential for survival (Aufderheide and Rodríguez-Martín, 1998). Linear furrows or grooves are created when the formation of the enamel matrix is disrupted across the tooth and no, or a reduced layer of, enamel is produced (Hillson, 1996). The defects appear as pits when only localised areas of the tooth are affected by disruption (Hillson, 1996). However, the maturation process is not affected (Hillson, 1996). When maturation is disrupted this leads to hypocalcification of the enamel, which shows as opaque white spots in the enamel (Hillson, 2005). Sometimes disruption to the enamel formation can lead to deformation of the crown. This is called a "gross defect" (Ogden et al., 2007). The defects can occur on every tooth but in they are most commonly recorded on the anterior teeth (incisors and canines)

(Aufderheide and Rodríguez-Martín, 1998). The crowns for all teeth, apart from the third molars, have formed by the age of seven (Reid and Dean, 2006). The formation of third molars are much more variable but the crown tends to be formed by the age of 15 years (Hillson, 2005). Dental defects can occur as a result of various factors, including malnutrition, infectious disease, chronic digestive disorders, and congenital defects (Goodman et al., 1987, 1988; Larsen, 1997; Boldsen, 2007).

Studies of past populations have found demographic differences in the distribution of DEH. Some research has found a lower than average age-at-death estimate for skeletons with DEH than those without, especially when the DEH is considered severe (Palubeckaité et al., 2002; Šlaus, 2008; Novak and Slaus, 2010). There are no consistent differences between males and females in different studies. Some studies have found no significant difference between the sexes (Palubeckaité et al., 2002), while others have found a predominance in males, and others a preference for females. When the males are affected more, this is usually attributed to males being more susceptible to stress than females (El-Najjar et al., 1978; van Gerven et al., 1990; Guatelli-Steinberg and Lukacs, 1999). On the other hand, when females are more strongly affected this is attributed to cultural practices protecting males from stress (Goodman et al., 1987; May et al., 1993; Gurri et al., 1996; Šlaus, 2000).

Studies have not found a systematic difference between urban and rural sites. In a study of three Lithuanian and Danish sites, Palubeckaité et al (2002) found no difference in prevalence between urban and rural sites. However, Garcin et al (2010) found an association between settlement type and prevalence rates in their study of early Medieval non-adult skeletons across Europe. In their study of the process of urbanisation of Nin in Croatia (12-15th century), Novak et al (2012a) found 44% of individuals displayed lesions in their incisors or canines. This is similar to previously reported rates for three different populations in medieval York (Grauer, 1989; Kemp, 1996; Holst, 2005). The analysis of different populations from medieval York has shown that there is no direct relationship between social status and the prevalence of lesions. St. Helen-on-the-Walls has a reported prevalence of 48%, while the populations of Fishergate House and St. Andrew, Fishergate report slightly higher rates with 52% and 59% affected, respectively (Grauer, 1989; Kemp, 1996; Holst, 2005) (See Figure 2.2).

Figure 2.2: Crude prevalence rates of dental enamel hypolasia in European sites



Stature

Final attained adult stature reflects a combination of genetic and environmental factors. For example, a study of twins from eight countries, Silventoinen et al (2003) have shown that genetic makeup is an important factor in attained stature in adult populations in affluent populations. Recent genomic analyses have also shown that hundreds of genes may contribute to final adult stature (Lettre, 2011). Growth retardation can also be associated with adverse "environmental" factors, although male stature appears to be more strongly affected by environmental stress than female stature (Stini, 1969; Ferembach, 1978; Wamani et al., 2007; Prendergast and Humphrey, 2014). As a result, the difference in sexual stature dimorphism may be smaller in stressed populations (Gustaffson, 2007).

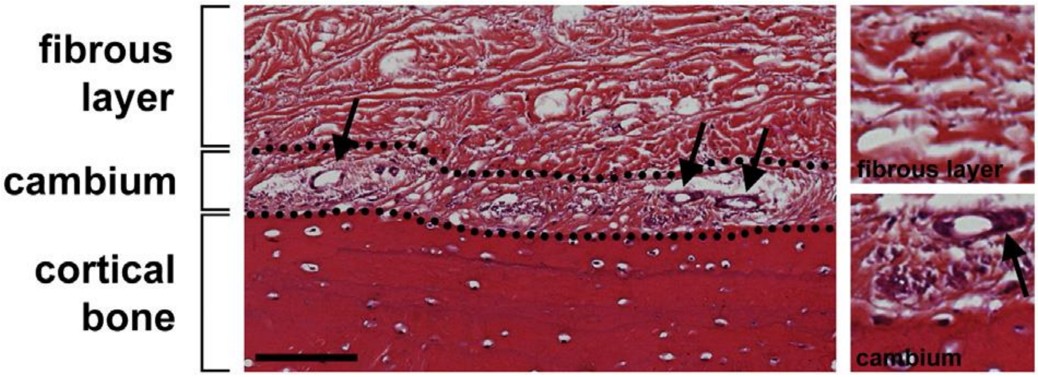
These environmental factors include food scarcity, malnutrition, micronutrient deficiencies, and a range of diseases, including infections (Allen, 1994; Ulijaszek, 1994; Black et al., 2008). In living populations, stunting is defined as smaller than two standard deviations from the average for the age of the person (WHO, 1995), and in some developing countries over half of the children younger than five years old may be affected by stunting (WHO, 2014). Even in developed countries such as the United States, growth retardation may be widespread among the poorest (Lewit and Kerrebrock, 1997). However, improvements in environmental conditions can lead to "catch-up growth" through increased growth rates and/ or delayed maturation (Adair, 1999; Gafni and Baron, 2000; Prentice et al., 2013). As a consequence, an episode of childhood stress ultimately may not have a significant impact on adult stature and therefore not be visible in skeletons from an archaeological context.

Baten and Murray (2000) found that urban stature in 19th century Germany was smaller than rural stature as a result of increased population density, density-dependent diseases and food shortages. Longitudinal studies of skeletal material have shown that average adult stature for males and females reduced in some European countries between the medieval period and the 19th century (Steckel, 2004; Maat, 2005; Cardoso and Gomes, 2009). Gustafsson et al (2007) found no significant changes in adult stature between the 10th and 17th century AD in Sweden. As the skeletons analysed reflect those who survived into adulthood, one of the limitations of this type of study is that those worst affected by environmental pressures would not have survived, and those that did survive may therefore have a greater than average stature than expected. Vercellotti et al (2014) showed this to be the case in their study of medieval Italy and Poland. Those with more “indicators of adaptation” were taller for one of the sites they studied. This is, however, not always the case. In St. Helen-on-the-Walls (York) the presence of lesions was associated with reduced stature (Grauer, 1989).

Non-specific periosteal reaction on the tibiae

The periosteum is a thin membrane of osteogenic and fibroblastic cells covering the external or cortical surface of most bones (Allen et al., 2004). Histologically, it is composed of two layers: a “fibrous” outer layer and an inner “cambium” layer as shown in Figure 2.3 (Allen et al., 2004; Roberts et al., 2015). It forms a transitional region between cortical bone and the overlying soft tissue. It serves as an attachment site for tendons, ligaments and muscles. The cambium also contains progenitor cells essential for bone growth and remodelling (Roberts et al., 2015). Anything that affects the cambium can lead to periosteal bone formation including trauma, infectious disease, metabolic disease (Kenan et al., 1993; Wenaden et al., 2005; Gosman et al., 2011).

Figure 2.3: Histological transection of the periosteum (Roberts 2014: 11)

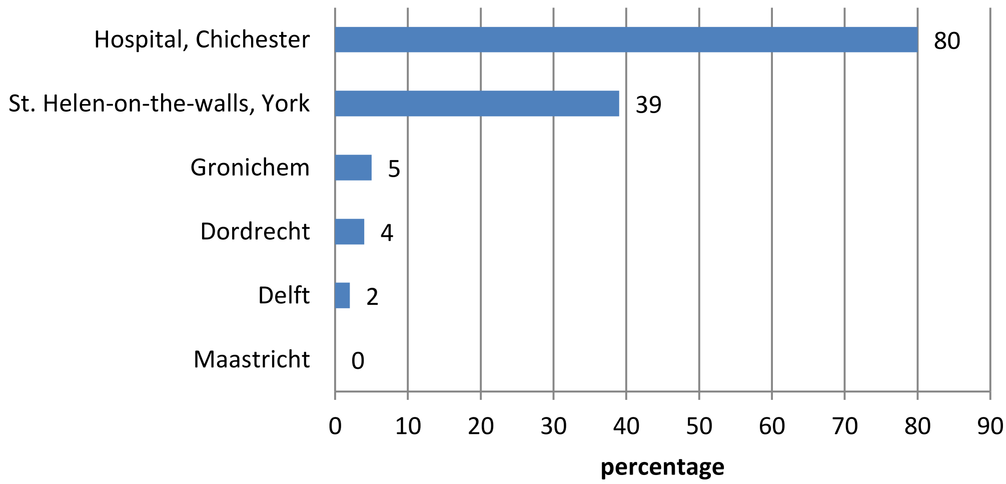


Acute inflammation will not leave traces on the bone, but if the inflammation persists for two to four weeks in adults new bone growth may occur (Wenaden et al., 2005; Lé et al., 2006). The type of bone formed may also provide information about the healing process (Weston, 2008; Roberts et al., 2015). When additional bone is laid down on the cortical bone surface, it appears porous and disorganised with a distinctive grey colour (Weston, 2008). This is typified as woven bone and when seen is taken to indicate the lesions reflect a condition (such as infection) that was active at the time of death (Weston, 2008). When the lesions are healing the woven bone remodels into mature lamellar bone. Lamellar bone is linearly organised and tends to have the same colour as the surrounding/underlying bone. When it is found in conjunction with woven bone it is suggested that the lesion was healing when the person died, and when found alone that the lesion healed before death, or that it represents multiple episodes of “insult” with different degrees of healing (Weston, 2008).

In bioarchaeology, the presence of periosteal new bone formation has been associated with infections, trauma, metabolic bone diseases, and bacterial infections in adults (Ortner, 2003, 2008; Roberts and Manchester, 2005; Weston, 2008, 2012; Klaus, 2014). In non-adults it can also be associated with normal bone growth (Weston, 2008, 2012), and specific patterns of these bone lesions have been associated with specific infections. These include: tuberculosis, leprosy, and treponemal diseases (Aufderheide and Rodríguez-Martín, 1998; Ortner, 2003; Roberts and Buikstra, 2003). However, other bone lesions in the skeleton are required to diagnose these specific diseases in skeleton (Weston, 2012). Furthermore, traumatic lesions are usually unilateral and focal (Weston, 2012). The majority of lesions in the skeleton cannot be linked to a single cause and the presence of non-specific periosteal new bone has often been interpreted as “stress” (Goodman et al., 1984; Grauer, 1993; Lewis and Roberts, 1997; Novak et al., 2012a; Klaus, 2014). Nevertheless, Weston (2009, 2012) has argued that “stress” would inhibit bone formation and that periosteal reaction should therefore not be interpreted in this way. In a recent article, Klaus (2014) argued that on a molecular level, some stress hormones would indeed inhibit bone formation, but that these are balanced by those that can stimulate bone formation. He therefore argues that “stress” can lead periosteal reaction and should not be dismissed entirely as a cause of periosteal bone formation (Klaus, 2014).

Previously reported prevalence rates in medieval populations are quite variable (see Figure 2.4), with Dutch populations at the low end with less than 10% (Maat et al., 1998; Onisto et al., 1998; Janssen and Maat, 2002; Maat, 2003). On the contrary, one of the poorest parishes of medieval urban York, the reported rate was much higher at 39% (Grauer, 1989). In contrast to these urban rates, the medieval leprosy hospital population buried at Chichester reported a prevalence of 80% in adults (Magilton et al., 2008). This high prevalence is due to the fact that leprosy may result in periosteal bone formation (Roberts and Manchester, 2005).

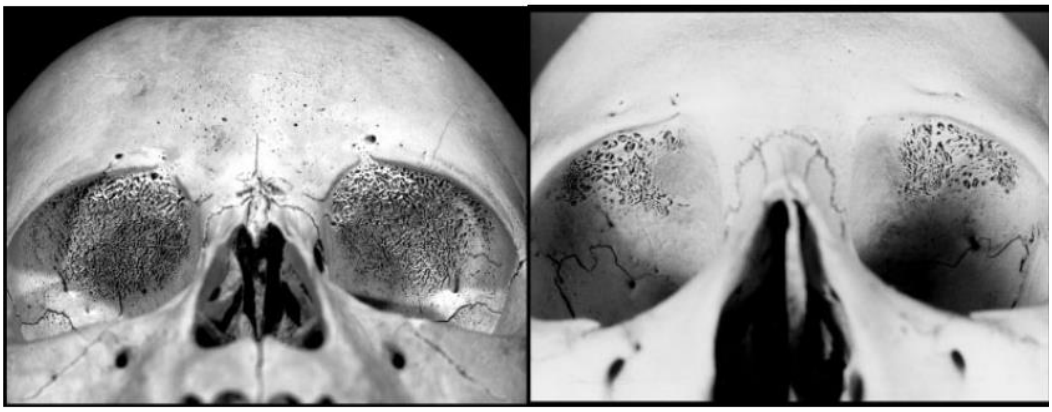
Figure 2.4: Variability in the crude prevalence rate of periosteal reaction on the tibiae



Cribra orbitalia

Cribra orbitalia describes bilateral lesions that occur on the orbital surfaces of the frontal bone. They develop as a result of an increase in red blood cell production (Stuart-Macadam, 1989; Roberts and Manchester, 2005; Walker et al., 2009). This results in an expansion of the diplöe and thinning of the outer table (Aufderheide and Rodríguez-Martín, 1998) leading to porosity of the orbits (see Figure 2.5). Porotic hyperostosis is a similar condition leading to lesions on the cranial vault (Walker et al., 2009). Sometimes the term porotic hyperostosis is used to refer both to the cranial and orbital lesions as they were considered to have the same aetiology (Stuart-Macadam, 1989; McIlvaine, 2013). The palaeopathological literature does, however, show that they may often have different aetiologies (Wapler et al., 2004; Walker et al., 2009). Lesions on the cranial vault were not recorded in this research as they are rarely seen in British populations (Roberts and Manchester, 2005).

Figure 2.5: Examples of active (left) and healed (right) cribra orbitalia lesions (Walker et al 2009: 110)



In the clinical literature, radiography and gross anatomical studies have shown an association between marrow hypertrophy of the cranial vault and hereditary haemolytic anaemias (Aksoy et al., 1966; Lanzkowsky, 1968; Agarwal et al., 1970; Moseley, 1974). These genetic conditions are, however, rare and do not explain the common presence of porotic hyperostosis and cribra orbitalia in skeletal material around the world (Sullivan, 2005; Djurić et al., 2008; Walker et al., 2009). As iron-deficiency anaemia occurs across the world (Bothwell, 1995), the presence of cribra orbitalia and porotic hyperostosis became almost synonymous with iron-deficiency anaemia in palaeopathology (Stuart-Macadam, 1985, 1992; Mittler and Van Gerven, 1994; Piontek and Kozlowski, 2002; Djurić et al., 2008). Nevertheless, this interpretation was sometimes challenged (Schultz, 2001; Wapler et al., 2004; Thillaud, 2008). However, Walker et al (2009) proved most decisive in rethinking the iron-deficiency hypothesis. They argued that anaemia leads to reduction in red blood cell production and would therefore not lead to marrow hypertrophy and suggested other nutritional deficiencies are more likely causes for marrow hypertrophy and especially a lack of B12 and/or folic acid (Walker et al., 2009). In response, Oxenham and Cavill (2010) argued that iron-anaemia could lead to marrow hypertrophy if erythropoietic activity (blood cell production) is ineffective instead of stopped completely and therefore premature to dismiss iron-deficiency entirely as an aetiological factor. Furthermore, deficiencies in iron and B12 often occur together (McIlvaine, 2013). Nutritional deficiencies can be caused by dietary deficiencies, malabsorption of the nutrients in the diet, and blood loss (Walker et al., 2009). Furthermore, Wapler et al (2004) showed that not all lesions recorded as cribra orbitalia resulted from marrow hypertrophy, but that 20% was due to subperiosteal bleeding. Subperiosteal bleeding can be caused by scurvy, rickets, hemangiomas and trauma (Woo and Kim, 1997; Sabet et al., 2001; Schultz, 2001; Ma'luf et al., 2002; Brickley and Ives, 2006). the aetiology of cribra orbitalia is therefore complex and multiple lifestyle factors (diet, economy, climate and hygiene) as well as infectious diseases may therefore be linked to the presence of these lesions (Stuart-Macadam, 1989, 1991, 1992; Grauer, 1993; Mittler and Van Gerven, 1994; Larsen, 1997; Piontek and Kozlowski, 2002; Wapler et al., 2004; Roberts and Manchester, 2005; Sullivan, 2005; Obertová and Thurzo, 2008; Walker et al., 2009; Novak et al., 2012a; McIlvaine, 2013).

The lesions normally occur bilaterally, and in adults they most often appear as healed lesions (Jacobi and Danforth, 2002; Wapler et al., 2004; Walker et al., 2009). Both the marrow hypertrophy and subperiosteal bleeding are more likely to occur in non-adults. In the case of marrow hypertrophy, the cranial vault bones are, together with the medullary cavity of long bones, the primary location of red blood cell production in childhood and adolescence. In adults red bloods cells are mainly produced in the axial skeleton (Walker et al., 2009). Orbital roof haematomas are more likely in non-adults because the periosteum is less well attached and the density of blood vessels connecting the periosteum to the underlying bone decreases with increasing age (Ma'luf et al., 2002). One notable exception is the medieval cemetery of St Helen-on-the-Walls in York, where active lesions were present in adults (Grauer, 1993). A higher prevalence in females is regularly reported (Stuart-Macadam, 1985; Fairgrieve and Molto, 2000; Wapler et al., 2004; Sullivan, 2005). This is usually explained by the higher nutritional demands on females associated with menstruation and childbirth (Sullivan, 2005). On the other hand, Paine et al (2009) reported a higher prevalence in males (48%) than females (37%) in the imperial Roman site of Urbino, although the difference was not statistically significant (Paine et al., 2009) .

Lewis (2002b) argues that the level of urbanisation in late medieval England would not have resulted in differences with rural areas, and that industrialisation would have led to a divergence in results from urban and rural contexts. Cribra orbitalia became less prominent in industrialised London in comparison with rural sites (Lewis, 2002b). A Swiss study found similar prevalence rates of cribra orbitalia in medieval urban and rural sites and did not identify an increase in the post-medieval period (Ulrich-Bochslerr et al., 2011). In a study of the Roman era, Gowland and Redfern (2010) found that London had higher prevalence rates than small towns and rural areas. They suggested that the urban-rural dichotomy may be too simplistic regarding cribra orbitalia

2.3.2 Bioarchaeological evidence of poor air quality

Sections 2.2.2 and 2.2.2 have shown that poor air quality can have a negative impact on health, and especially respiratory health. This section will therefore focus on recognising respiratory health from skeletal material using the presence of maxillary sinusitis (upper respiratory tract) and rib lesions (lower respiratory tract).

(i) ***Maxillary sinusitis***

The two maxillary sinuses are the largest air-filled cavities underlying the soft tissues of the face (see Figure 2.6). They are situated in the facial bones above the maxillary alveolar bone and below the orbits. The inside of the maxillary sinus is lined with cilia, covered mucous membrane whose function is to move mucus through and out of the sinuses (Slavin et al., 2005). The sinuses drain into the nasal cavity through the sinus ostia (drainage hole) which is located about two-thirds up the medial wall (see Figure 2.7) (Hauman et al., 2002).

Figure 2.6: Facial bones and paranasal sinuses (Jones, 2001, p 11)

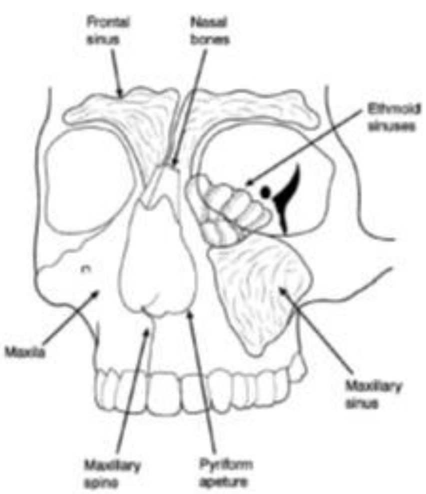
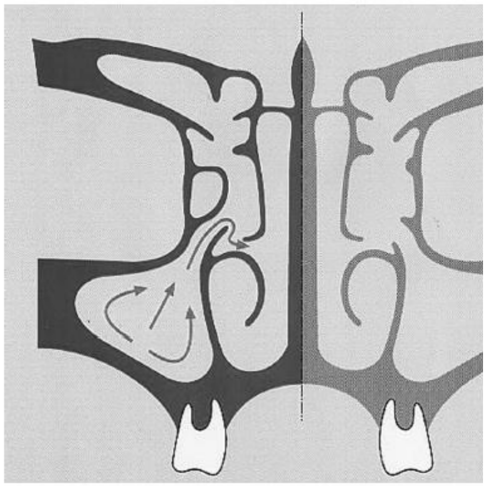


Figure 2.7: Maxillary clearance (Jones 2001, 17)



The functions of the paranasal sinuses are poorly understood, but many have been suggested (Hauman et al., 2002, p 128):

- humidification and warming of inhaled air,
- assisting in regulating intranasal pressure,
- increasing the surface area of the olfactory membrane,
- lightening the skull to maintain proper head balance,
- imparting resonance to the voice,
- absorption of shocks to the head,

- contributing to facial growth,
- existing as evolutionary remnants of useless air spaces

Obstruction of the sinus and/or its drainage may lead to a decrease in pressure inside the sinus, which may predispose to the development of sinusitis (Hauman et al., 2002; Slavin et al., 2005). There are three classifications of sinusitis according to duration: acute (less than 4 weeks); sub-acute (4-12 weeks) and chronic (more than 12 weeks) (Mahoney and Rosenfeld, 2007). Bone changes are unlikely to occur in the acute form, but may develop when the sinusitis lasts for a longer period.

The causes of sinusitis are not well understood by clinicians examining living patients (Slavin et al., 2005). First, general health and genetic predisposition may affect its prevalence (Bascom and Kesavanathan, 1997; Kern et al., 2008; Hsu et al., 2013), and maxillary sinusitis becomes more prevalent with increased age. Bascom and Kesavanathan (1997) have shown that in the United States today chronic sinusitis affects 129 per 1000 people overall. This increases from 60 per 1000 in individuals less than 18 years old to 140 per 1000 people for individuals of 65 years and older. Clinical studies have also shown that females are more likely to be affected (Ugincius et al., 2006; Arias-Irimia et al., 2010). Dental disease has been shown to be one of the causes of maxillary sinusitis. The bone between the bottom of the tooth socket and the maxillary sinus is very thin. The tooth may therefore project through the sinus floor (Jones, 2001), and therefore inflammation of the sockets from caries or peri-apical lesions can also therefore very easily spread to soft and hard tissues of the sinus (Hauman et al., 2002). Clinical research has shown that 10-40% of sinusitis could result from dental disease (Mehra and Jeong, 2009; Simuntis et al., 2014). The role of micro-organisms in the development of sinusitis is currently unclear as the same viruses, bacteria and fungi have been found both in individuals with and without sinusitis (Brook, 2011). Furthermore, air pollution can also lead to irritation of the airways and thus result in respiratory disease including maxillary sinusitis (for a more detailed explanation see section 2.2.2 and 2.2.3 above).

Clinical studies focus mostly on the involvement of soft tissue in sinusitis. However, bone remodelling has been show to occur as a result of chronic inflammation and is associated with recurring episodes of sinusitis (Bhandarkar et al., 2013). In bioarchaeology, the appearance of maxillary sinusitis has been described in detail by Boocock and coworkers (1995) as pitting and/or additional bone growth on the interior sinus walls. The majority of maxillary sinusitis studies in Europe (see Figure 2.8) have been undertaken in England (Boocock et al., 1995; Lewis, 2002b; Bernofsky, 2010). However, prevalence rates have also been reported for The Netherlands (Panhuysen et al., 1997), Germany (Sundman and Kjellström, 2013a) and Sweden (Sundman and Kjellström, 2013a). Even though medieval urban sanitary conditions have been reported as notoriously poor (Addyman, 1989; Leguay, 2002a; Clark, 2009), prevalence rates for rural sites have been reported as being as high as those reported for urban sites (Lewis et al., 1995a; Roberts, 2007; Sundman and Kjellström, 2013a). For example, a 34% frequency in skeletons was reported for Wharram Percy, England (Lewis et al., 1995a). However, this rises to 50% when only the adults are included (Lewis et al., 1995a). Urban rates reported vary between 34% in skeletons from Fishergate House, York and 63% at St Helen-on-the-Walls, also in York (Lewis et al., 1995a; Papapelekanos, 2003). High levels have even been reported in Canadian hunter-gatherers. Merrett and Pfeiffer (2000) reported a 50% prevalence rate for people buried in association with a 15th century Iroquian site (including non-adults). This has been linked to their smoky houses (Merrett and Pfeiffer, 2000).

Figure 2.8: Crude prevalence rate of maxillary sinusitis in Europe

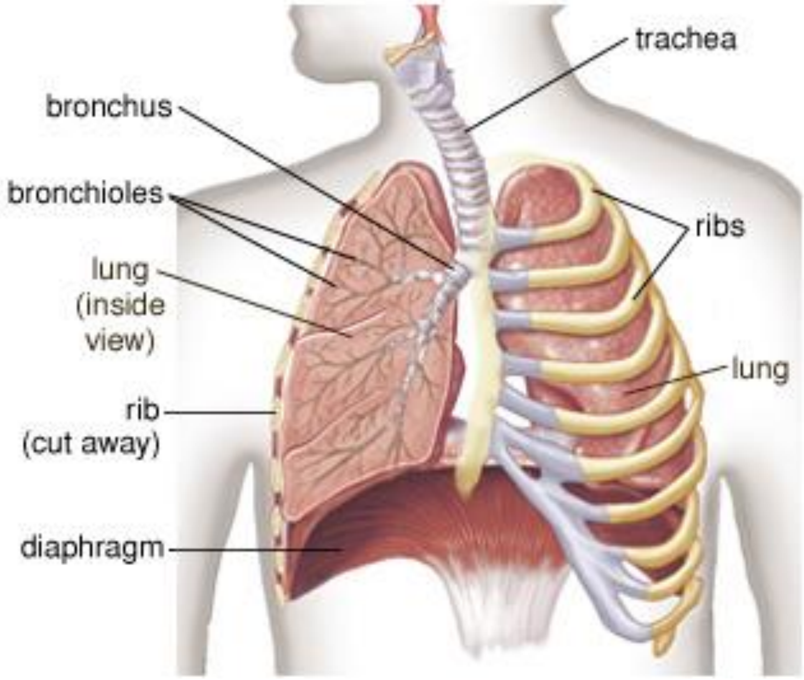
The higher levels of sinusitis found in females today (see above) has not always been replicated in bioarchaeological studies. Some studies have reported no statistically significant difference between males and females (Boocock et al., 1995; Lewis et al., 1995b; Bernofsky, 2010), while one study found a higher prevalence in males (Sundman and Kjellström, 2013a). A higher prevalence of maxillary sinusitis has been reported in multiple sites (Panhuysen et al., 1997; Roberts, 2007; Sundman and Kjellström, 2013b). Roberts (2007) found that differences between males and female prevalence rates were greater in rural populations and that prevalence rates were more similar in urban environments. When differences exist, they have been explained through differences in the working environment and exposure to pollutants

(Roberts, 2007; Sundman and Kjellström, 2013a). Dental disease is also commonly reported alongside the maxillary sinusitis evidence (Panhuysen et al., 1997; Roberts, 2007; Bernofsky, 2010; Liebe-Harkort, 2012). However, even when dental disease is present, this does not necessarily mean that the dental disease caused the maxillary sinusitis. Only when there is a direct connection between the dentition and the sinus can a direct link between the dental disease and maxillary sinusitis be hypothesised (Roberts, 2007)

(ii) ***Periosteal reaction of the ribs***

The impact of the environment on respiratory disease has been discussed above (Sections 2.2.2 and 1.2.3). The lower respiratory tract comprises the trachea, bronchi, bronchioles, alveoli; lungs and diaphragm (see Figure 2.9). The majority of the lower respiratory tract is therefore situated in the chest and surrounded by the rib cage. Between the lungs and the ribs there are two pleural membranes – the pulmonary pleura attached to the lung and the visceral pleura attached to the ribs. The space between them is called the pleural cavity. Disease can affect either the pleura (fluid build-up in the pleural cavity or inflammation of the fluid between the pleural membranes) or the lungs. Infections affecting the lungs are many and include tuberculosis, bronchitis, brucellosis, pheumonia, myscoses, cyptococcosis, nocardiosis, histoplasmosis, blastomycosis and actinomycosis (Albert et al., 2008). Furthermore, ribs can be affected by direct trauma (Levine et al., 2009).

Figure 2.9: Lower respiratory system
(http://www.britannica.com/EBchecked/topic/499530/human-respiratory-system - Accessed online on 27 January 2015)



In a clinical setting, the presence of signs and symptoms and abnormal changes in the soft tissues are more important for making a diagnosis, and the ribs themselves are obviously not subject to direct analysis, as in bioarchaeology; therefore, there is little information available on the prevalence of rib lesions in living populations. However, radiographic studies have shown that chronic inflammation of the lungs or pleura can cause thickening of the ribs (Eyler et al., 1996; Guttentag and Salwen, 1999). Guttentag and Salwen (1999) described new bone formation in individuals with early stages of respiratory disease.

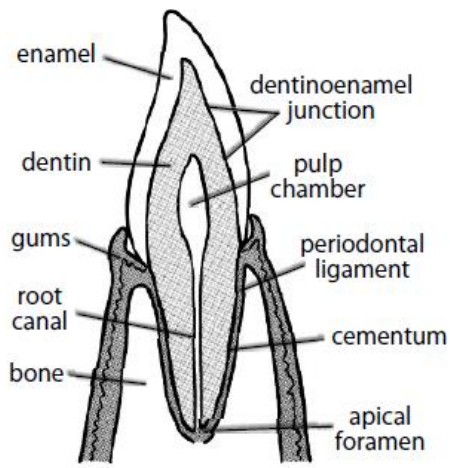
Few bioarchaeological studies have looked at the presence and frequency of periosteal lesions on the visceral surfaces of the ribs. Some studies have looked at identified in late 19th/early 20th century skeletal populations with known causes of death. They found that rib lesions are common in skeletons with tuberculosis as a cause of death and that tuberculosis is the most likely cause in many instances (Kelley and Micozzi, 1984; Roberts et al., 1994; Matos and Santos, 2006; Santos and Roberts, 2006). However, the lesions are not pathognomonic for tuberculosis (TB) and alternatives suggested include pneumonia, chronic pleural disease, bronchiectasis, brucellosis, cancers, non-specific osteomyelitis, treponemal disease and fungal diseases (Molto, 1990; Eyler et al., 1996; Roberts et al., 1998; Matos and Santos, 2006). Studies looking at identifying tuberculosis DNA in skeletons with periosteal rib lesions have been done (Mays et al., 2002; Nicklisch et al., 2012), but even if the DNA is present, it does not necessarily mean that tuberculosis caused the lesions (Roberts, 1999). Overall, the presence of these lesions may therefore be interpreted as indicators of “respiratory disease” (Pfeiffer, 1991; Lambert, 2002).

In bioarchaeology, the prevalence of periosteal rib lesions has rarely been reported outside England. However, Bernofsky (2010) provided a comprehensive summary of the prevalence of rib lesions throughout time from the Iron Age to the post-medieval period. She found that the prevalence increased with time, especially from the medieval period onwards. She linked this increase to less well ventilated houses and an increase in indoor activities (Bernofsky, 2010). No prevalence rates have been reported in Europe for the late medieval period, but Capasso (2000) reported a 11.6% prevalence of periosteal rib lesions in skeletons from Herculaneum (AD79) and Nicklisch (2012) reported in 35% of skeletons in early Neolithic Central Germany.

2.3.3 Dental disease

The human adult dentition normally exists of 32 individual teeth, divided into four quadrants. In a normal dentition the following teeth can be found in each quadrant: 2 incisors, 1 canine, 2 premolars and 3 molars. Every tooth consists of a crown, which has a layer of enamel on the outside and dentine on the inside, and one or more roots (see Figure 2.10)

Figure 2.10: Anatomy of a human tooth (White et al 2011: 104)



There are multiple diseases that can affect the teeth, but in this study, the primary purpose of recording dental disease (caries and periapical lesions) in this project was to exclude it as a cause for maxillary sinusitis.

(i) ***Caries***

Caries, also known as dental decay, is the progressive demineralisation of the dental tissue (Hillson, 2005). Caries lesions are the result of fermentation of sugars in the diet by bacteria in dental plaque. The acids produced erode the tooth enamel (Hillson, 1996). Once the enamel is eroded, the acids can also affect the dentine underneath (Hillson, 1996). Caries develop from white/brown spots into cavities in the enamel or dentine, and is the leading cause of ante-mortem tooth loss today (Ismail, 1997; Hillson, 2008). The initial discolouration may take years to develop into a cavity (Liebe-Harkort et al., 2010). Caries can affect the crown, cervix or the root (Brothwell, 1981; Ismail, 1997; Chazel et al., 2005; Hillson, 2008; Wasterlain et al., 2009), but most often affects the areas between teeth and the cervix as they are most often affected by plaque deposits (Hillson, 2001). Not all teeth are affected equally; the molars tend to be affected more often as their surface is more complex, thus easily trapping food remains (Hillson, 2001). Additionally, the maxillary dentition tends to be affected slightly less than the mandibular dentition (Hillson, 2001). The left and right side of the mouth tend to be affected in the same way and the prevalence of caries can therefore reliable be inferred if only the one side of the mouth is present (Hillson, 2001). A link with increasing age follows logically (Ismail, 1997; Hillson, 2001; Chazel et al., 2005).

The onset of caries is affected by a multitude of factors including dietary composition and frequency, absence of proper oral hygiene, socio-economic status, salivary bacterial load, immunoglobulins, fluoride intake, and genetics (Hillson, 2008; Lucas et al., 2010; Targino et al., 2011; Shakya et al., 2013). Furthermore, the presence of dental enamel hypoplasia may predispose to the development of caries lesions (Ismail, 1997; Targino et al., 2011; Shakya et al., 2013). A diet rich in carbohydrates is a very strong predisposing factor in the development of lesions (Hillson, 2008; Liebe-Harkort et al., 2010; Lucas et al., 2010). Moreover, females are more susceptible to developing caries than males, and this may be due both to cultural as well as genetic factors (Lukacs, 2011).

In skeletons from an archaeological context, caries has been found at low in frequencies in hunter-gatherer populations (Larsen, 1995, 1997; Lukacs, 2011). A first increase is seen with the adoption of agriculture (Lukacs, 2011). In Britain, Moore and Corbett (1973) found no significant differences in caries in the 2000 years from 550 BC until the start of 16th century AD, even though the prevalence of caries in Anglo-Saxon (400 AD- 1066 AD) had a lower prevalence than the preceding Roman period (43AD-410AD) and the subsequent late medieval period (1066-1500 AD) (Moore and

Corbett, 1973). Reviewing published and unpublished data across time, Roberts and Cox (2003) described the same trend of higher caries prevalence rates in Roman and late medieval times, with lower rates in Anglo-Saxon times (Roberts and Cox, 2003). Sugar was introduced in Britain in the 12th century, but would only have been able for the elite until prices dropped towards the end of the late Medieval Period (Moore and Corbett, 1973). As the prices of sugar dropped in the following centuries, it would have become available to increasing numbers of the population (Woodward and Walker, 1994; Schofield, 2006; Woolgar, 2006). Chazel et al (2005) found no difference in caries prevalence rates between the 4th – 11th century AD and the 12th-15th century AD, but did find a significant increase in the 16th and 17th century, associated with the more widespread use of carbohydrates and sugars in the diet.

The analysis of caries in archaeology is hampered by taphonomic factors and ante-mortem tooth loss. Taphonomic effects include staining of the enamel and post-mortem tooth loss. As a result of the former, most bioarchaeological studies only record the advanced (cavity) stage (Ismail, 1997; Hillson, 2001; Liebe-Harkort et al., 2010). Furthermore, it is not possible to know if teeth lost ante-mortem or post-mortem displayed lesions (Hillson, 2001, 2008), thus affecting the interpretation of prevalence rates.

(ii) ***Periapical lesions***

Periapical lesions are cavities in the bone of the mandible or maxilla related to the tooth root apices. The term includes granulomata, cysts and abscesses, which cannot be distinguished in dry bone. Furthermore, lesions with different aetiologies may be present in the same individual and even merge, leading to confusion in diagnosis (Ogden, 2008). Granulomata are small lesions (under 15mm in diameter) as a result of the accumulation of granulation tissue around the root apex. They are supposedly painless and undetected unless radiographed (Hillson, 2005). Cysts are larger than granulomata, but often develop from them. They are fluid-filled cavities - surrounded by a thin bone shell - which grow slowly (Dias et al., 2007). Nevertheless, the size of lesions alone is not reliable for distinguishing them from granulomata (Hillson, 2005). Abscesses can be acute or chronic. The difference is in the speed of pus accumulation around the root. Both acute and chronic abscesses tend to drain through the dental tissues and therefore rarely lead to bone changes (Hillson, 2005). For example, Vier and Figuerdo (2002) in their study of the prevalence of various periapical lesions in living patients found that cysts accounted for 24.5% of the lesions, and non-cystic periapical abscesses accounted for almost two thirds (63.7%) of the data.

The presence of periapical lesions indicates that the dental pulp has been dead for some time (Ogden, 2008). Dental pulp dies as a result of direct exposure to the oral environment. Exposure is most commonly caused by dental caries, but dental wear or trauma to the tooth, both exposing the pulp cavity, can also be causes (Dias and Tayles, 1997; Hillson, 2005; Ogden, 2008; Lucas et al., 2010). The lesions are most common in molars and they increase with increasing age (Boldsen, 1998; Lucas et al., 2010). Lucas et al (2010) failed to find periapical lesions associated with the canine teeth. The use of radiography in recording lesions in archaeological material significantly increases the number of lesions recorded (Djurić and Rakočević, 2007; Lucas et al., 2010). In a longitudinal study in southern France, Chazel et al (2005) found an increase in periapical lesions with the time periods (4th-11th centuries AD, 11th-15th centuries AD, and 16th-17th centuries) in parallel with an increase in caries. Despite dental care in modern populations, periapical lesions were still more prevalent in their modern sample (Chazel et al., 2005).

2.3.4 Summary

The second half of this chapter has reviewed previous research on interpreting “health” from skeletal material. It first discussed non-specific indicators that have been widely used to interpret the level of “stress” in a population. Secondly, it has reviewed skeletal evidence of respiratory disease as a proxy of air quality in these populations. There is no evidence of distinctly urban-rural patterns in these skeletal lesions in late medieval Europe. Other sources of evidence are therefore required to interpret the prevalence rates of skeletal indicators. The historical and archaeological evidence is therefore discussed in the next chapter.

2.4 Conclusion

This chapter has reviewed the impact of living in an urban environment on human health. While there are advantages and disadvantages to living in an urban environment, it has identified factors that may have affected the health of urban dwellers in the past. Poor sanitary conditions, air pollution and poor quality housing can all contribute to a variety of diseases. Furthermore, it has shown that socio-economic status, diet and climate will affect the prevalence of disease in a population. This chapter has also identified skeletal indicators that can identify the ability of people to cope with these stressors in these populations (cribra orbitalia, dental enamel hypoplasia, stature, and periosteal rib lesions) as well as respiratory disease (maxillary sinusitis and periosteal rib lesions). However, as these lesions have complex aetiological factors and cannot therefore be linked to health directly, the next chapter will discuss the historical and archaeological evidence for late medieval urban health in NW Europe.

3.1 Introduction

So far, this thesis has shown that rapidly developing urban centres face multiple challenges, which may impact on the health of the inhabitants. It has also shown that the meaningful interpretation of skeletal lesions requires contextualisation. This chapter therefore aims to use historical and archaeological data to review how the challenges affecting health in urban contexts today were met in Caen, Canterbury and Ghent. As only limited information is available from these towns specifically, further information is drawn from their regions and other contemporary European towns. Even though there are differences between regions and individual towns, certain trends in urban development can be traced across Europe (Scholkmann, 2011). Based on the issues raised in the previous chapter, the following themes are addressed for late medieval NW Europe in this chapter:

- **Climate**: The late medieval period is marked by a significant shift in the climate in the 14th century. From the 9th to 13th century, the climate in NW Europe was relatively stable and conducive to population growth. After the 14th century the climate was much more unpredictable (Büntgen et al., 2011). The impact of this climate change on each of these populations is discussed.
- **Socio-economic status**: in the previous chapter it has been shown that poverty in modern populations has a strong impact on the experience of a person's life and that it usually has a negative impact on health (Van de Poel et al., 2007). The socio-economic status of the skeletons could therefore affect the prevalence rates of the lesions recorded in this study and the socio-economic status of the populations contributing to the cemeteries studies is explored.
- **Urban environment (anatomy of an urban settlement)**: every settlement develops along a unique trajectory based on economic success, population size and density, and the topography. These factors lead to unique challenges for every settlement and the response affects the health of the inhabitants. This section explores the population size and density, and topography of Caen, Canterbury, and Ghent.
- **Economy, industry and trade**: The economy is an essential part of the success and failure of a town or city. The occupations of the inhabitants will affect levels of pollution, waste produced and water needed. This section therefore reviews the evidence from the late medieval economies of Caen, Canterbury and Ghent.

- **Urban environment (living and working conditions)**: Sanitary conditions are directly related to human health. Chapter 2 has shown that providing healthy living conditions is still a challenge for urban centres today, especially in the developing world. The quality of housing, water and waste management, personal hygiene and air quality in Caen, Canterbury and Ghent are therefore revised.
- **Food supply and diet**: Urban settlements do not produce enough food to sustain their population (Ruel et al., 2010). However, under-nutrition and malnutrition lead to nutritional deficiencies (Black et al., 2008). The food supply chain for Caen, Canterbury and Ghent are therefore discussed here including food production within each town and its effect on health.
- **Migration**: Chapter 2 has shown that migration is an important vector in the spread of disease (Alirol et al., 2011). The extent and direction of migration in late medieval Caen, Canterbury and Ghent are therefore explored.

3.2 Climate

Climate research for this period relies on environmental archaeological data and contemporary historical texts (Galloway, 2009; Guiot, 2012). For medieval North-West Europe, dendrochronology is an important archaeological source of evidence for climate (Haneca, 2005; Haneca et al., 2005; Büntgen et al., 2011; Diaz et al., 2011). The width of tree rings, especially oak, provides information about precipitation and temperature (Haneca, 2005). In European oak, wider rings are associated with milder winters and harsh winters with smaller rings (Haneca et al., 2009). Extreme weather events can be traced across Europe in this period (Büntgen et al., 2011). Documentary evidence for the medieval period includes direct observations of the weather in documents as weather diaries, letters, annals, and chronicles. Indirect evidence (e.g. length of frost periods, freezing of waterways, quality and timing of harvests) can also be gleaned from accounts from town councils, ship cargos, agriculture, as well as the use of water-and windmills (Van Engelen et al., 2001; Shabalova and Van Engelen, 2003).

Historical and archaeological evidence suggest that the temperatures and precipitation in Kent, Normandy and Flanders would have been comparable during the late medieval period (Shabalova and Van Engelen, 2003; Chuine et al., 2004; Diaz et al., 2011; Graham et al., 2011; Pribyl et al., 2012). The period of interest is generally divided into two climatic cycles: the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA). The dating of these periods does, however, vary between studies. The MCA dates from around the 10th century to the 14th century AD when the climate was more stable (Büntgen et al., 2011). The average temperature was warmer than the Late and post-Roman period before and the LIA afterwards (Galloway, 2009; Wilson et al., 2013). The weather would generally have been warmer with milder winters (Goosse et al., 2012). The relative stability of the climate meant better crop yields, and also that otherwise unhospitable land could be cultivated (Behringer, 2010). As this led to a rapid expansion of the population, the climate at this time is considered a contributory factor in the expansion of medieval urban centres (Galloway, 2009; Mouhot, 2013). However, the warmer weather also had a negative consequence as it leads to an increase in bacteria, mosquitos and host animal species (McMichael, 2012). For example, it can be considered a factor of the rise and fall of leprosy in the medieval period (Duncan, 1994). Furthermore, Malaria-carrying mosquitos became endemic as far north as England (Behringer, 2010). Malaria was introduced into England during the Roman period and may have been endemic in marshy areas in the Anglo-Saxon period (410-1050AD) (Gowland and Western, 2012).

The climate deteriorated by 1300 AD leading to the LIA which lasted until the 19th century. However, the LIA was not a consistently cold and dry period, but a time of unstable weather (Mouhot, 2013). There were years where the trees blossomed as early as January (Leguay, 2002a), but in general the winters tended to be more severe than the preceding MCA. For example, the 1430s in Flanders were characterised by very strong winters, lots of rain, high water levels and warm summers (Lievois, 2008), and the precipitation and temperature changes may have been swift. Furthermore, storm surges in the North Sea, which were rare in the MCA, became more prevalent (Galloway, 2009).

This climate change led to years of failed crops at the start of the 14th century, resulting in a Europe-wide famine (1315-1317) which may have lasted up to seven years in some areas (Galloway, 2009; McMichael, 2012). The weather led to failed crops in the years 1315-1317, but European agriculture only recovered completely in 1322 (Dyer, 2005). In Bruges 10% of the population may have died in this famine (Clark, 2009). This famine also led to economic disruption, poverty and unemployment (Clark, 2009). The combination of a population weakened by famine and extreme flooding in the 1340s have been described as contributory factors in the severity of the European Black Death pandemic in 1348-49 (Butzer, 2012; Mouhot, 2013).

Flooding, which increasingly occurred from the 13th century onwards (Gerrard and Petley, 2013), had devastating effects. Immediate effects would include the loss of life, damage to buildings and industrial equipment and possessions (Leguay, 2002a). Furthermore, sources of potable water can become contaminated, leading to outbreaks of disease. Repairing the damage would have been expensive and extra taxes may have been raised to cover the costs for the municipality (Leguay, 2002a). Despite historical evidence, in Europe no casualties of flooding and other natural disasters have been identified in the archaeological record (Gerrard and Petley, 2013). However, in Asia, evidence of earthquakes has been claimed in archaeological urban contexts between the 8th and 15th century AD in Kyrgyzstan and Kazakstan (Korjenkov et al., 2003, 2006, 2012). Earthquakes may have affected the Mediterranean, but are unlikely to have had a strong impact on North-West Europe (Clark, 2009). Nevertheless, an earthquake is reported to have occurred in Kent in 1342 (Hicks and Hicks, 2001), among others.

The similar climate in Caen, Canterbury and Ghent (see Figure 3.1 and Figure 3.2) means the towns would have been similarly affected by the change from the WMA to the LIA. Although climate would therefore not have led to differences in health between the populations investigated here directly, different responses to harvest failures and natural disasters could indirectly have led to differences between populations.

Figure 3.1: Global hydroclimate for the period 950-1400AD. Blue ovals indicate predominantly wet wetter while red ovals indicate predominantly dry weather (Diaz 2011, 1496).

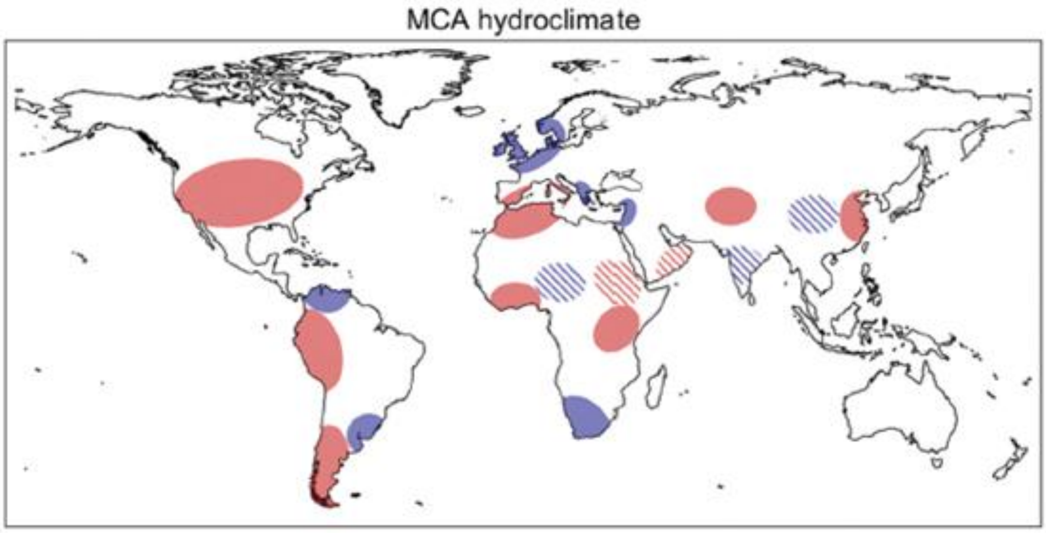
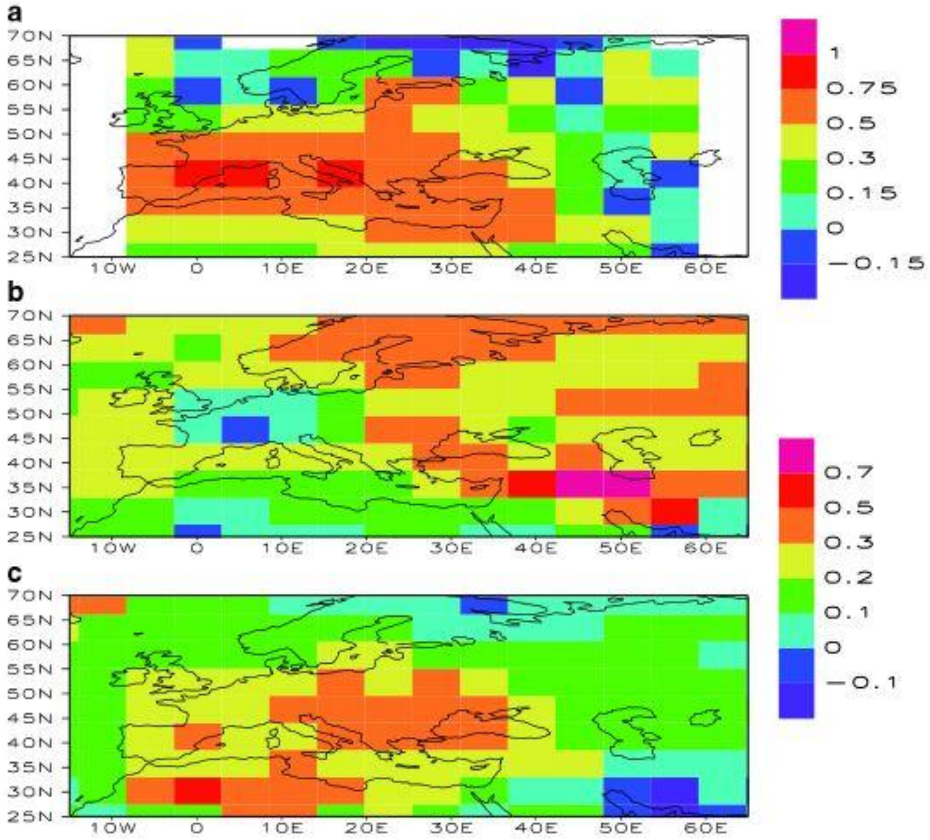


Figure 3.2: Difference in surface temperature from April to September between the MCA and LIA using different models: a)reconstruction of Guiot et al (2010), b) ASSAM-MANN and c) ASSAM-GUIOT (Guiot et al 2012, 40)



3.3 Socio-economic status

In the previous chapter (section 2.2.1) it has been shown that socio-economic status affects all aspects of urban life and has a noticeable effect on health in developing as well as developed countries (Brender et al., 2011). The presence of poverty is often difficult to assess in past populations from archaeological material culture alone as the poor leave less material culture than the elite (Orser, 2011). For example, the medieval stone houses that survive would have belonged to the elite, and no examples of the housing of the poor remain standing today (see below) (Grenville, 1997, 2008; Pearson, 2007; Clark, 2009). Historical documents (e.g., wills, tax payments and records from care-giving institutions) are therefore useful in identifying the level of poverty in a settlement and the aid relief available (Dyer, 2012).

The late medieval poor were not a homogeneous group but included people who were affected by illness or disability, widows, people with poorly paid jobs and people who had fallen on hard times due to external circumstances, such as a poor harvest, warfare or even taxation (Dyer, 2012; Van Steensel, 2013). From the mid-14th century distinctions were made between the deserving (e.g. widows, people who had fallen on hard times) and the undeserving poor (beggars and vagrants) (Clark, 2009; van Bavel, 2010; Rawcliffe, 2013; Van Steensel, 2013). Poverty was common in urban centres with 50-70% of the population described as poor (Clark, 2009; Fontaine, 2013; Van Steensel, 2013). The streets of Ghent were reportedly swamped with poor people early in the 14th century (Clark, 2009).

Poverty was unequally distributed within a settlement. This is illustrated by tax records from 17th century York. They show that approximately 25% of households in York were exempt of paying tax. Nevertheless, this rose to 39% and 46% of households in the poor parishes of All Saints Peaseholme and St. Saviour's, respectively (Giles and Jones, 2011). Medieval suburbs are also generally believed to have been poor (Schofield and Vince, 2005).

Poverty relief in towns was provided as a combination of money and alms in kind from a variety of sources: town councils, religious institutions, guilds and fraternities, and donations from wealthy benefactors. How these were distributed depended on the region. For example, In France and Flanders care was provided through parishes and town councils, but this was not present in England (Rawcliffe, 2013). The distribution of alms was rarely effective in the long term. For example, in Ghent, St Peter's Abbey only provided poor relief on holy days, and this was therefore mostly a symbolic gesture (Haemers and Ryckbosch, 2010)

Hospitals emerged in urban centres across NW Europe, from at least the 11th century. For example, the foundation of a hospital for the poor has been attributed to William the Conqueror in the 11th century (Musset, 1981a) and St John's hospital in Canterbury was founded in 1084 (Sweetingburgh, 2010b). They were founded by princes, urban councils, religious institutions and other benefactors. Initially the hospitals throughout NW Europe were mostly aimed at the poor and travellers (Haemers and Ryckbosch, 2010; Rawcliffe, 2013). However, some hospitals might specifically exclude certain subpopulations. St. John's hospital in Canterbury, for example, strictly forbade the entrance of cripples, the blind, the feeble, the old and the impotent (Sweetingburgh, 2010b). Increasingly, the hospitals in NW Europe only catered for the middle and upper class as they tried to balance the books (e.g., Haemers and Ryckbosch, 2010). In many institutions entrance fees were therefore introduced to avoid admitting the poorest (Dobson and Edwards, 2010; Sweetingburgh, 2010b) By the 14th and 15th century, Flemish religious hospitals predominantly cared for their inmates and their mostly wealthy relatives (Haemers and Ryckbosch, 2010). Furthermore, to cover the cost of running these institutions, a number of beds would be rented out as care homes for the elderly (Rawcliffe, 2013), and lay people in these hospitals often had to work in return for their stay (Sweetingburgh, 2004; Arnoux and Postel-Vinay, 2013). Only a limited number of institutions were founded in the 14th century (Sweetingburgh, 2010b).

Specialised hospitals also emerged. Leprosaria were the most common and emerged on the borders of urban centres (Roffey, 2012), but there were also institutions for other groups such as the blind (e.g. in Caen and Ghent), lunatics, orphans, and the elderly (Musset, 1981b; Nicholas, 1987; van Bavel, 2010; Dyer, 2012; Van Steensel, 2013) These specialist hospitals were often run similarly to general hospitals, discussed above, and again aimed at the richer part of the population. For example, the leprosarium founded in Ghent only admitted people with substantial wealth, and poor people with leprosy were commonly known as the “field sick” as they lived in huts and open fields (Nicholas, 1992). Throughout Europe, leprosaria declined in the 14th and 15th century, as leprosy became less prevalent. Some institutions were converted into almshouses (Roffey, 2012). Almshouses or *Maison Dieu* became more common in the 14th century. They were either privately run by a wealthy benefactor or collectively by guilds, fraternities or parishes. The private ventures would often disappear with the death of the benefactor, and those run by guilds only cared for their own members (Rosser and Dennison, 2000; Rawcliffe, 2013).

In Flanders, the town council provided a limited but constant supply of poor relief. It distributed mostly corn, bread and peat, but more in times of food shortage (Haemers and Ryckbosch, 2010). The Flemish Count regularly donated money towards poor relief to town councils. In addition, when the count was in town he would give personal gifts, financial or in kind. Twenty-five to 50 people per year received personal gifts in this way (Haemers and Ryckbosch, 2010). In the 15th century the count restricted the towns’ poor relief as aid was given to those who did not really need it (Haemers and Ryckbosch, 2010). The town council also supported people undertaking charity, for example taking care of foundlings (Nicholas, 1992).

Heilige Geesttafels (Holy Ghost Tables) were another source of poverty relief in the Low Countries. These were run at a parish level by lay individuals. They distributed food, made small loans and buried the poor. They were, however, selective in their assistance and thus mostly provided care to the middle and upper classes, and funding mostly came from private benefactors (Haemers and Ryckbosch, 2010). In the 15th century begging was prohibited in Ghent unless people had been given permission by a Holy Ghost Table (Nicholas, 1992). In addition to institutionalised care, money or alms were sometimes given out on special occasions. For example, some individuals provided in their will for a number of paupers to be given a penny for attending their funeral (Dyer, 2012).

Poverty would have been common in Caen, Canterbury and Ghent and is therefore likely to have affected the cemetery populations used in this research. In Canterbury, the cemetery of St. Gregory's buried both parishioners from the parishes of St. Mary and Northgate, but also inmates of St. John's hospital for the poor and infirm. As the hospital excluded certain afflictions, they may not have been truly poor. Nevertheless, this could affect the results in this study. In Ghent, the St. Pieter parish was reasonably prosperous in the north and very poor in the south (Nicholas, 1987). The socio-economic status of the individuals included in this study may therefore vary depending on where they lived within the parish. No information is available about the socio-economic status of the population that contributed to the cemetery used in this research. As the parish spanned as much as 25% of the town (Huard, 1925), socio-economic status within its boundaries would have been variable.

In summary, poverty was very common in medieval towns and there were many initiatives to help the many poor in medieval urban centres with the widest diversity of charitable institutions in Flanders. In reality, however, the charity was often misdirected and only provided for the 'deserving poor' or even the wealthy (Rosser and Dennison, 2000; Van Steensel, 2013). The influence of poverty on people's life experience and health will be discussed in the relevant sections below.

3.4 The urban environment: The anatomy of an urban settlement

From the 8th century AD onwards, the population in Europe grew exponentially. As a consequence, existing settlements grew and became urbanised, and new settlements emerged. Canterbury had already been a regional capital in Roman times, but both Ghent and Caen were new settlements that emerged in the 9th century (Jean-Marie, 1999; Laleman, 2008). Even new settlements grew from largely rural beginnings into urban ones and the rural origins may have been visible in the urban landscape for a long time. A survey of urbanisation in the Netherlands from the 10th to 14th century shows that rural architecture had a long-term impact on the infrastructure of towns (see section 3.6 on buildings below) (Sarfatij 1990).

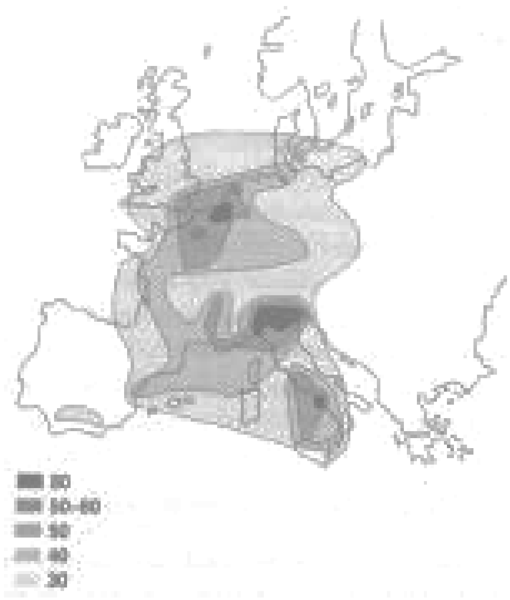
Slowly these settlements developed urban characteristics that would have impacted on the health of its inhabitants. This section therefore describes the general appearance of late medieval towns in Europe – their size, density and layout – with a special focus on data available for Ghent, Canterbury and Caen. The influence of towns on their hinterland will be discussed below (see section 3.6 – the economy).

The subsequent section then focuses on the economy of each town before discussing the living conditions within the settlement.

3.4.1 Settlement size

In Europe, Italy led the urbanisation and the largest settlements there reached over 400 hectares in the 13th century, with population size estimates of over 100,000 individuals (Hubert, 2004). North-West Europe was the next most urbanised region in Europe, especially Flanders and northern France (see Figure 3.3) (Hubert, 2004; van Bavel, 2010). England remained relatively rural, but Kent was one of the most densely occupied regions of the country (Sweetingburgh, 2010a). However, the towns in NW Europe did not reach the same size as those in Italy as towns were overall closer together and had smaller hinterlands (van Bavel, 2011). For example, Ghent reached a size of 80 Ha with a population of approximately 64,000 people in the middle of the 14th century (Blockmans and Prevenier, 1999; Laleman and Vermeiren, 2010). During the expansive centuries of the 11th to 13th century, Caen would have had a population size of at least 10,000 individuals and a settlement area that covered c. 35-55ha (Jean-Marie, 1999; Leguay, 2002b; Gauthiez, 2010). Canterbury reportedly had a population of at least 6000 living within the walls at Domesday in 1066 (Lawson, 2004) and this would have grown significantly in the subsequent centuries (Mate, 2010a). However, it has to be stressed that these population estimates are fraught with difficulties (see 1.6 – urban definition). First, these numbers are from different centuries/periods and with the rapid expansion up to the 13th century and contraction in the 14th century, these estimates should only be considered a guide. Also, these estimates are based on taxes payable by every household. It makes assumptions about the size of an average household and some part of the population would have been exempt (e.g. clergy, the poor) (Leguay, 2002b). Furthermore, the size of a settlement is difficult to estimate. The town walls cannot be considered accurate reflections of the town size (Scholkmann, 2011). In Canterbury, for example, the late medieval town walls still followed the Roman outline, but densely populated suburbs were found outside (Urry, 1967; Schofield and Vince, 2005). In Ghent, on the other hand, the defences were expanded multiple times (for example, seven times in the 13th century), incorporating rural areas in anticipation of future growth (Laleman and Vermeiren, 2010). As a result, the town defences are not an accurate reflection of the size of either town.

Figure 3.3: Urbanisation in Europe in 1500 relative to Venice (Blockmans and Hoppenbrouwers 2007: 219)



3.4.2 Population density

The population density within each settlement varied over space and time. When these towns developed houses would have been relatively large and spacious. However, as the population size grew, individual plots would have reduced in size and rooms within houses may have been let separately (Verhulst, 1999; Rees Jones, 2008). The population density in most towns would have reached its peak in the 13th century before the Great Famine (1315-1317) and Black Death (1348-1349) in the 14th century decimated the European population (Dyer, 2005; Clark, 2009). Canterbury may have lost half of its population due to the Black Death (Méar-Coulstock, 2010). As a result of this population contraction, the population density decreased, with larger plots and houses for those who survived (Britnell, 1991).

Mortality crises due to disease or famine were common throughout Europe in the Late Medieval Period (Clark, 2009), but would have increased from the 14th century onwards as a result of the climate change (see section 1.2) and the arrival of the plague. As malnutrition has a negative impact on health and the immune system (Van de Poel et al., 2007), the famine at the start of the 14th century may have contributed to the high mortality of the Black Death in the 1340s (Mouhot, 2013). Famines, the diet, and availability of food are discussed in more detail below. Records from Christ Church priory in Canterbury indicate regular mortality crises between 1395 and 1505, although they became less frequent in the last 50 years of that period (Rawcliffe, 2013).

Caen was hit by the plague for the first time in 1348-1349 (Jouet, 1981a; Leguay, 2002b), but it is unclear how badly it was affected, the death-toll in Normandy varying between 15% and 60% of the population (Favier, 1970a). From then onwards until the 17th century, epidemics did revisit the town regularly (Favier, 1970a; Jouet, 1981a; Angers, 2006). In the 15th century the plagues were so extensive that the Darnétal parish had to expand its cemetery twice (Angers, 2006). In the 17th century, there were fewer epidemics and, when they took place, they were less lethal (Bardet et al., 1970a).

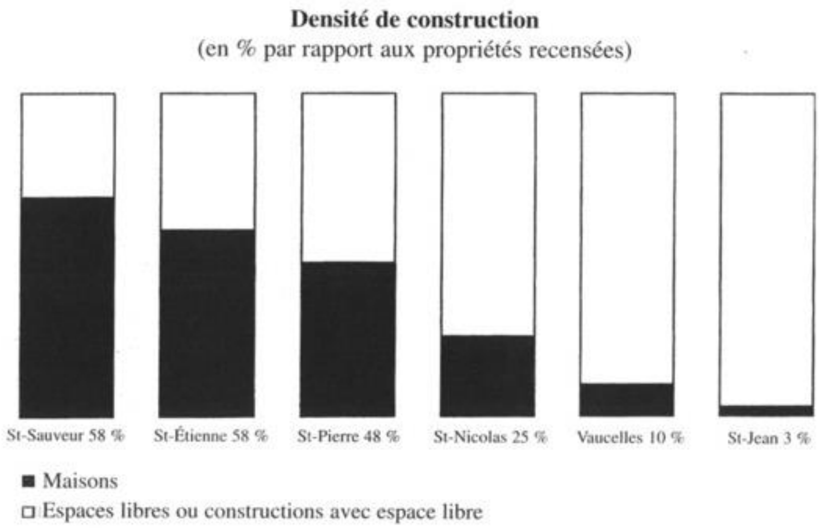
Several years of famine were recorded in Flanders in the 12th century (Nicholas, 1992). Ghent may have been less susceptible to famine than the rest of Flanders from the 14th century, as it acquired dominance over all grain trade in Flanders (the so-called "grain staple"), and grain could only be sold outside the town once the needs of the town were met (Nicholas, 1987). Grain was predominantly imported from France, but sometimes supplemented with German grain (Nicholas, 1992). It appears that Flanders was not affected as badly by the first wave of the plague in the 1340s, and was much worse affected by a second wave in the 1360s (van Bavel, 2010). However, the documentation related to these years was destroyed at the end of the late medieval period and information is scant (van Bavel, 2010). The plague episodes became less common in the 15th century (Nicholas, 1992), and Flanders recovered quickly with relatively strong population growth in the 15th and 16th centuries (van Bavel, 2011).

In addition to disease and famine, population size would also have been affected by warfare. For example, the population of Douai reportedly shrank from 20,000 to 10,000 individuals during the Hundred Year War (Leguay 1999). Caen's population was also affected by the same war. However, refugees from the surrounding countryside may have reduced the effect (Angers, 2006).

Population density would also have varied within a settlement. For example, the town walls of Ghent were expanded seven times in the 13th century in anticipation of continued growth (Laleman and Vermeiren, 2010). As a result, some areas within the defences would have been more rural than others, and the St. Pieter suburb in particular has been described as having a rather rural character until the 18th century (Verhulst, 1999; Van Houtryve, 2013). Suburbs were actually a common feature in many towns, as today, and they could be extensive. In Winchester in the 16th century, approximately half of the population reputedly lived in suburbs (Kermode, 2000), and Canterbury developed large suburbs outside the city walls in the 11th and 12th centuries (Urry, 1967; Schofield and Vince, 2005). The suburbs in late medieval

European towns were generally industrial in character and were mostly relatively poor (Schofield and Vince, 2005). The following industries were often found in the suburbs: smiths, potters, tanners and fullers (Keene, 1990; Galloway et al., 1996).

Figure 3.4: Population density in the parishes of Caen in the 14th century (Delente 2000, 394). (maison: houses, espaces libres ou constructions avec space libre: open spaces or buildings with open space).



Household size, and associated population density, would have varied depending on the industry/trade of the owner and his/her wealth. For example, in Coventry the average household size was 7.4 for merchants, 4.2 in the metal trade, 3.2 for the building trades and 1.8 for households headed by women (mostly widows) (Schofield and Vince, 2005). Nevertheless, large household size does not equate to crowding (see Chapter 2), as the size of the houses would have varied and crowding is measured in individuals per room or floor space per individual (Zhang and Chen, 2014). However, based on modern evidence (see Chapter 2), it is likely that the poor would have lived in crowded conditions and thus have potentially increased exposure to people with a transmittable disease (Prüss-Üstün, 2006).

3.4.3 Topography of the urban settlement

Urban centres were characterised and shaped by natural features (e.g. rivers, topography) but also by human-made structures (town walls, main buildings and roads) (Schofield and Stell, 2000; Schofield and Vince, 2005). During the 13th century the spatial organisation of Flemish towns changed dramatically (Boone, 2002), in Ghent the street plan was redesigned and new market places were created (Stabel, 2000).

Town walls had many functions, including defence, controlling the population within the walls and levying tolls. Sometimes the gate houses would also have other functions (for example, they were sometimes used to keep prisoners). Increasingly they were also a manifestation of civic pride (Clark, 2009). Unfortunately, the walls also blocked waste run-off, and drainage holes in the town walls were often inadequate (Leguay, 2002a). This would have affected sanitary conditions within the town (see below). Canterbury's defences follow the Roman outline and at least three Roman gates were reused (Schofield and Vince, 2005), while Ghent's defences were regularly expanded (Laleman and Vermeiren, 2010). In Caen, the defences built in the 11th century fell in disrepair by the 14th century and were therefore ineffectual in defending the town at the start of the Hundred Year War (Musset, 1981b).

As early as the 7th century AD, but certainly by the 10th century AD, buildings may have become organised 'in urban fashion' along the street in England, Flanders and York, with houses being built perpendicular to the street and the small end facing the street instead of parallel to the street (Schofield and Vince, 2005).

Medieval streets have a reputation for being small and winding (Leguay, 2011). However, Laleman and Vermeiren (2010) argue that the archaeological evidence in Ghent indicates wider streets, with regular open spaces as a result of market squares and gardens. These streets in NW Europe were most commonly paved using stone, wooden planks or gravel (Jørgensen, 2008; Clark, 2009; Rawcliffe, 2013), stone being by far the most expensive, but also the most durable (Jørgensen, 2008). In some towns only the streets with the most traffic would be laid in stone, while other towns would use stone more widely (Jørgensen, 2008). For example, there is evidence of cobbles being used in side streets in York in the 12th century, while Norwich used gravel at the same time (Rawcliffe, 2013). While paving would differ from one town to another, the town's streets were, however, usually the same with a gutter running through the middle of the street (Jørgensen, 2008). The cleanliness of the street will be considered in section 3.6.3 below.

In many towns, industries would not be evenly distributed throughout the settlement. Many industries would cluster within the settlement (Kermode, 2000; Rawcliffe, 2013). For example, documentary evidence from Ghent indicates a clear congregation of workers in the same occupation within sections of the town. This included: carpenters, drapers, mercers, fishmongers, smiths, goldsmiths and leatherworkers (Nicholas, 1987; Schofield and Vince, 2005). Sometimes this was the result of the needs of the particular industry. For example, the butchers in Caen congregated along the river Odon (Neveux, 1997), while related industries tended to cluster together. Other industries were purposefully kept apart (Schofield and Vince, 2005). However, some industries would be banned to the suburbs due to their polluting nature. However, due to the expansion of the town there would still be a mixing of residential and industrial activities (Schofield and Vince, 2005; Rawcliffe, 2013). Not all occupations would have been segregated in this way. In Ghent, for example, bakers and brewers would have been found throughout the town (Nicholas, 1987).

3.5 Economy, industry and trade

The growth and decline of each town is dependent on its economy. In comparison with rural areas, the urban economy is more diverse, relies less on agriculture, and more on trade and industry (Giles and Dyer, 2007). The economic development is unique for every town as it depends on interaction with other towns. This section therefore first provides an overview of the economic development of Caen, Canterbury and Ghent throughout the late medieval period within a European context. Industry and trade are then each discussed in more detail.

3.5.1 Economy

The economy of urban areas would have been closely interlinked with that of the surrounding countryside (Jean-Marie, 2010). However, the urban economy would have been more focused on industries and trade than that of rural economies (Giles and Dyer, 2007). The service sector would also have played a major part in the urban economy. For example, in Ghent in the mid-14th century approximately 11% of the town’s population worked in the service sector (Clark, 2009).

Guilds and fraternities emerged in many towns and cities as a way to organise a trade or industry within a settlement (Clark, 2009; Blockmans, 2010). For example, some of the guilds in the textile sector had thousands of members (Blockmans, 2010). Furthermore they played a large part in public and cultural life (Stabel, 2004). The guilds in Flemish cities were extremely powerful and they were involved politically (Stabel, 2004; van Bavel, 2010). In other regions guilds were much less developed and did not gain the power of the Flemish guilds (Clark, 2009)

The European economy was badly affected by the Great Famine in 1315-1317 and the arrival of the Plague in 1348-1349. However, some regions in Europe were affected worse than others. For example Normandy (Caen) was badly affected by the arrival of the Plague, while the Flemish economy had already resumed growth by the end of the 14th century (Nicholas, 1992). Furthermore the reduction in population size led to a drop in rents and prices, but it also concentrated wealth (Clark, 2009).

(i) ***Caen***

Caen's economy started to grow rapidly in the 11th century following interest from the Norman Dukes (Musset, 1981a). Religious powers soon followed (Musset, 1981a) and by the start of the 12th century Caen had risen to become a *de facto* second capital in Normandy (Musset, 1981a; Neveux and Bouet, 2006). Furthermore, even after the Anglo-French war of 1200-1204 where Normandy was annexed to France, Caen still had contact with England (Jean-Marie, 2010). The prosperity continued throughout the 13th century, but in the 14th century a decline set in (Favier, 1970a; Jouet, 1981a; Leguay, 2002b). In addition to warfare, epidemics and harvest failures, the economy was hit by efforts to centralise economic activity around Rouen in an attempt to create a worthy rival to Antwerp in Flanders. Caen was badly affected as a result and it took until the 16th century for the town's economy to revive. This recovery was tentative at first, but more rapid in the 17th century, although it was not the same unbridled growth from the start of the period (Jouet, 1981b; Neveux, 1981a).

Normandy's economy varied according to region. Coastal towns tended to be dedicated to fishing and trade, while the more inland towns were dedicated to administrative and religious functions (Favier, 1970a). Furthermore, prosperity at the start of this period led to expansion and the rise of living standards, but close regulation of business and a lack of a wage increase meant prosperity and expansion only affected those that enjoyed economic independence (Favier, 1970a).

(ii) ***Canterbury***

Canterbury was a busy market town (Rawcliffe, 2013) and religion played a large part in its economy. It became the first Episcopal See in Britain in the 6th century AD, a position of religious power it has maintained throughout the centuries (Méar-Coulstock, 2010). Very quickly after Archbishop Thomas Beckett was murdered in 1170, a cult following emerged and Canterbury became an important place of pilgrimage far beyond English shores for the next three centuries (Lincoln, 1955; Duggan, 2010). The status of Canterbury as a place of pilgrimage brought much to the economy (Gelin, 2010). First, pilgrims needed a place to sleep and eat. Christ Church offered some free lodging to the poor, but most pilgrims would have had to find their own accommodation (Duggan, 2010). Furthermore, there was an extensive trade in memorabilia such as ampullae and pilgrim badges (Duggan, 2010). The pilgrimages ended when the shrine of Saint Thomas was destroyed during the reformation (Webb, 2004; Duggan, 2010). After the Reformation, Canterbury became the head of the Church of England (Méar-Coulstock, 2010).

(iii) ***Ghent***

The economy of Ghent was strongly focused on the production of textiles and their trade, and it has been estimated that over 60% of the population worked in textiles (Van Houtryve, 2013). This was especially so in the area of Saint Peter's where the majority of individuals worked as weavers or linen workers (Nicholas, 1992). Until 1358 the village of St Peter in Ghent had a separate organisation for textiles, apart from Ghent (Nicholas, 1992).

With the decline of the textile industry in the 14th century, the economy of Ghent relied more and more on their influence over the grain trade in Flanders through "the grain staple" (Nicholas, 1992; van Bavel, 2010). Staples centralised the trade of foreign products in Flanders within one town in the 14th and 15th centuries. The grain staple was located in Ghent and meant that Ghent controlled all the grain that entered Flanders (Nicholas, 1992). This staple did not restrict farmers to buying grain just in Ghent. However, grain for resale had to go through the staple and export was prohibited until the towns' needs had been met (Nicholas, 1992). Due to the staple, the price of grain was more stable than elsewhere (Howell and Boone, 1996) and, after the population decrease in the 14th century, Ghent usually had a surplus (Nicholas, 1992).

The Flemish economy managed to "weather the storms" of the 14th and 15th century well. The Count of Flanders managed to avert the worst of the Great Famine (1315-1317) by providing his population with cereal grain from the Baltic and encouraging the growth of peas and beans, which could be harvested more quickly. When the economy was again hit hard by the Black Death (1348-49), Flanders was largely spared and the Flemish economy actually grew again late in the 14th century (van Bavel, 2010). Even though Ghent was still important it lost out to Bruges for international trade, and Antwerp gained in importance.

Flemish towns, including Ghent, gained much independence from the ruling elite in the 12th century (Dumolyn and Haemers, 2005; Blockmans, 2010). Ghent obtained juridical and political autonomy in 1128 (Dumolyn and Haemers, 2005), while by the 15th century the independence of Flemish cities was much more restricted (Arnade, 1997). Similarly, English towns also acquired some autonomy between the 12th and 15th centuries (Attreed, 1992), but very few to the level of Flemish towns (Rigby and Ewan, 2000)

3.5.2 Industry

A great variety of industries have been described for Caen (Jouet, 1981a), Canterbury (Urry, 1967; Duggan, 2010) and Ghent (Nicholas, 1987). Most of these industries would have been replicated in every town as they were necessary for the needs of the urban population. For example, butchers, bakers, cooks, fishmongers, cheesemongers, etc. would have been present to attend to the dietary needs of the population. Other industries attended to material needs: builders, smiths, tanners, etc. and a last category provided services such as washerwomen (Leguay, 2002a). Some of these would have contributed significantly to the pollution of the environment. For example, butchers would slaughter animals within the town walls. The refuse was not always cleared properly, entrails and blood may have been littering the street in some towns (e.g., Namur in Belgium - Lentacker et al., 1997) providing ideal conditions for zoonotic diseases to spread (Nwanta et al., 2008). By the 14th century butchers were heavily regulated in most English towns with severe restrictions on where they could dispose of waste (King and Henderson, 2013; Rawcliffe, 2013). In Paris, the river Seine was used for dumping animal waste. The accumulation of waste in the Seine was so bad that it was barely possible to breathe on the river banks and historical documents attest to people making a detour to avoid the area (Leguay, 2011). The butchers sold animal hide to tanners or tawyers depending on the animal concerned (Cherry, 1991). Tanners and tawyers would then clean the hide and turn them into different types of leather depending on the animal and part of the skin (Michel, 2014). To do so, many chemicals were required including (but not limited to) urine and animal faecal matter as well as bark, alum, fermenting rye and stale beer (Cherry, 1991; Leguay, 2002a). A modern study in Indonesia shows that exposure to chemicals lead to skin diseases (Febriana et al., 2011) and a cohort study of Italian tanners has shown elevated levels of various cancers (lung, bladder, etc) as a result of exposure to these chemicals (Iaia et al., 2006). For some archaeological sites, the use of the area as a tannery has been suggested based on the animal, plant and insect remains, tanning pit structures, and even place names (Cherry, 1991; Hall and Kenward, 2003; Duncan, 2006; Bartosiewicz, 2009; Lebrasseur, 2010). Chemicals were also used in the production of textiles (Walton, 1991).

The fuel used by industries requiring fire in their occupation (e.g., smiths, bakers, cooks), would lead to air pollution. In the 13th century, coal was introduced in southern England and imported from Newcastle and from there it was distributed to Rouen and beyond (Brimblecombe, 1976; Keene, 2012). As this was a ‘dirty’ fuel it was mostly restricted to industrial use. Even then, bakers and cooks avoided using it as it affected the taste of the food (Brimblecombe, 1976). Furthermore, smiths in London restricted their working hours as the working conditions were considered too polluting (Brimblecombe, 1987). Working in such polluted areas would have increased the prevalence of respiratory disease.

Industries were not equally distributed throughout a settlement and zoning was common in late medieval towns in NW Europe (Leguay, 2002a). For example, industries requiring vast amounts of water (e.g. tanners, textile producers) were often found near rivers (Keene, 2012). Furthermore, related industries were often found to have settled close together. However, this zoning would not have applied to all industries, and some would have been found throughout a town. For example, in Ghent bakers were typically found throughout an urban centre to serve the community (Nicholas, 1987). Moreover, by the 14th century industries considered polluting were often pushed into the suburbs. Norwich's comprehensive list of industrial polluters included various processes in the textile and leather industry as well as butchery and brewing (Jørgensen, 2010a; Ciecieznski, 2013). The sanitary conditions and air pollution would therefore have varied throughout a town based on the occupations being practised in the vicinity. The cemeteries from Caen and Canterbury used in this study come from central areas in the town, while Ghent's cemetery population derived from an industrial suburb (see Chapter 4).

As the type and intensity of industry varies between each town, the following subsections discuss the towns investigated here individually. Very little is known about Canterbury's industry as the economy was strongly focused on trade and economic activities related to pilgrimages (e.g. lodgings, ampullae), but it had a local dominance over the textile Caen was also had a local distribution of its textiles, but apart from that also was involved in the international export of the local stone. Ghent is the most industrialised of the three towns and was strongly specialised in the textile industry. Every town is now discussed in a little more detail.

(i) ***Caen***

Caen was predominantly a redistribution centre for the local hinterland, especially after the 14th century. The only exception is the distribution and working of the local stone. The textiles produced in the town would have had a local distribution.

Caen's Stone

The first major industry around Caen was mining of the local stone. The stone gained popularity after it was championed by William the Conqueror in the 11th century to build the castle and the two abbeys in Caen (Dujardin, 2010). After ascending the

English throne, the stone got an international reputation that lasted the centuries (Dujardin, 2010). Despite Normandy's annexation to France in the 13th century and the wars between the countries, the interest in Caen's stone was only temporarily reduced. However, it remained very much in demand in the south of England from the mid-13th century until the 17th century (Jouet, 1981a; Musset, 1981a), but mining the stone only ceased completely in the 20th century. Apart from the raw material, Caen also started to sell finished decorative pieces in the 13th century (Musset, 1981a).

Textiles

Throughout Europe the production of textiles was an important industry (Munro, 2003), and this also applied to Caen and Normandy from the 13th century (Bardet et al., 1970b; Musset, 1981b). At its peak, Norman textiles could be found throughout Europe. Even though there is evidence of Caen's textiles as far away as Italy (Musset, 1981b), Caen's textiles had mostly a local distribution (Jouet, 1981a). Plants for dying textiles were grown in and around Caen and a small amount of wool was produced in Caen itself (Musset, 1981b). From the 14th century, the textile industry declined in Caen although it remained an important part of the local economy (Jouet, 1981a). Lace making was often integrated with charity works in hospitals and within religious communities as it was a profitable way to occupy abandoned children (Bardet et al., 1970b).

Definitely no later than the middle of the 16th century, Caen resumed Its textile industry, and diversified into the manufacture of cloth woven with local wool, (Jouet, 1981b). The tradition was sufficiently strong to last into the 16th and 17th centuries when other industries in the region were faltering, although it is difficult to monitor through the 16th -18th centuries (Jouet, 1981b).

Metallurgy

Metallurgy also has a long history around Caen, and included producing a variety of household utensils, tools, "cart tracks" and items related to warfare (e.g. armour, canons) using Spanish and local iron as well as English tin and lead (Jouet, 1981a; Leguay, 2002b). However, metalworking would likely have taken place in the suburbs (Rawcliffe, 2013)

(ii) ***Canterbury***

A variety of occupations have been described as present in Canterbury (Mate, 2010a). However, the economy of the town was focused on activities associated with the pilgrims (e.g. lodging, souvenirs) (Urry, 1967). Goods manufactured in the town were distributed within its hinterland (Mate, 2010a). An official mint was installed in Canterbury in the 8th century AD (Méar-Coulstock, 2010). At the start of the 12th century, Canterbury was an important location for minting, with seven mints. This was similar in size to London at the time, which had eight (Méar-Coulstock, 2010). However, in 1180 Canterbury was deprived of all its mints, although the ecclesiastical mints were restored during the reign of King Richard (Duggan, 2010).

(iii) ***Ghent***

In 14th century Ghent 75% of the population was involved in manufacture (Nicholas, 1987) and over 60% worked in the textile industry. In the St. Pieter parish, the predominant occupation was weaving. Although brewers were found throughout the city, this was also a major occupation in this area. Tanning occurred in a nearby suburb (Nicholas, 1987).

Textiles

In the 11th century Flanders became known for long heavy cloths called *panni* (Nicholas, 1992). At this time the Flemish textile industry was largely based on domestic wool production. In the 12th century this was supplemented by fine English wool as the domestic supply became insufficient (Nicholas, 1992). By the end of the 13th century the English started charging customs on wool exports, thus leading to a price rise in Flemish cloth (Nicholas, 1992). Early in the 13th century, Flemish textiles were so popular that production was often outsourced to the countryside (Nicholas, 1992). However, towards the end of that century, the fear of counterfeited goods meant that production moved back to towns (Nicholas, 1992). In 1302 and 1314, Ghent had the privilege to prohibit the manufacture of woollen cloth within 30km of its walls, granting exceptions to a few smaller towns through charters (Nicholas, 1992).

The textile industry in Ghent declined sharply in the 1350s. The Flemish urban artisan producers refused to use new technological advances which increased production 20 to 50 times because they believed it compromised quality (Nicholas, 1992; van Bavel, 2010). In the 11th century they had successfully adapted to the use of linen instead of wool, but they did not adapt to the change from linen to silk and velvets in the 14th century (Nicholas, 1992). There was a revival of the textile industry in the first half of the 15th century with England as the most important outlet of Ghent's linen (Howell and Boone, 1996). At this time there was a shift to the use of Spanish and Scottish wool as well as lower quality English wool (Howell and Boone, 1996). The textile industry declined again in the 16th (Nicholas, 1992).

Leather

Ghent was the only substantial producer of leather in Flanders. It exported leather from the 10th century AD (Nicholas, 1992), and by the 15th century, it had developed a strong trade in leather gloves and purses (Nicholas, 1992). The late medieval leather industry was very polluting and has been discussed above. However, the St. Pieter parish (from where the skeletons in this study originate) was mostly focused on textile production, but there was a tannery in a neighbouring parish (Nicholas, 1987). Pollution associated with tanning may therefore have affected the inhabitants of St. Pieter occasionally.

3.5.3 Trade

Few industries were present solely in towns and would have relied on interaction with the rural hinterland. However, trade was one of the major functions of an urban settlement and towns were dominant centres in their regions (Schofield and Vince, 2005). Italian cities had a strong influence over vast hinterlands (Hubert, 2004). In Flanders and northern France there was a denser distribution of towns and each town therefore had influence over a smaller area. Ghent had significant influence a 40-50km radius (Nicholas, 1987, 1992). In England the urban centres were more dispersed than in France or Flanders. However, Canterbury had a relatively small hinterland as (40-50km) in comparison to other English towns of a similar size (Keene, 2000; Galloway, 2001).

The range of goods traded varied depending on the size of the town (Schofield and Vince, 2005). For example, for many goods Caen relied on imports from the bigger centres of Rouen and Paris (Jouet, 1981a). Ghent, on the other hand would have been dominant within its region. Throughout north-west Europe there were hierarchies between urban centres based on trade. At the top of these hierarchies were centres which were involved in long-distant trade (Schofield and Vince, 2005).

Another place for trade would be markets and fairs (Schofield and Vince, 2005). From the 13th century onwards English royals tried to standardise weights and measures used (Schofield and Vince, 2005), while the French and Flemish fairs offered protection to all those attending for the duration of the fair and sometimes safe passage to and from the fair, thus encouraging short-term migration (Blockmans, 2010).

(i) ***Caen***

Caen developed into an important local redistribution centre early in the 11th century

(Musset, 1981a), and remained locally important throughout the turmoil in the following centuries (Jouet, 1981a). Apart from the weekly market which was established from the 11th century, there were a few large fairs organised annually (Musset, 1981a). The October one was the most important, but at least two more were organised by the abbeys (Favier, 1970b), but they ceased in the 15th century to centralise trade around Rouen (Favier, 1970b)

International trade with Caen varied significantly over time. In the 11th-12th century, Normandy played a key part in trade, including Caen. In addition to the stone (see above), Norman textiles were distributed across Europe. However, continual warfare in Normandy in the 14th – 16th centuries regularly interrupted international trade (Favier, 1970b). For example, trade with England was periodically prohibited or impossible (Favier, 1970b). The difficulty in sailing along the Orne from Caen to Ouisetram (the closest port to Caen), and restrictions on the places where boats could dock, added to the problem (Jouet, 1981a). The international character of trade was therefore much reduced, and it was mainly the stone that was still exported directly from Caen (Grant, 2005).

(ii) ***Canterbury***

Christ Church in Canterbury owned over half of the private properties in the city centre by the 13th century. The properties would mostly be rented out as both shops and houses (Clark, 2000). By the middle of the 13th century, there were at least 200 shops in Canterbury (Urry, 1967; Duggan, 2010), and more than half of those owed rent to Christ Church (Duggan, 2010). In addition, there were a variety of markets, including for cattle, fish, butter, timber, oats and salt (Urry, 1967; Duggan, 2010). Nevertheless, many trade deals were done privately, for example with treaties for the sale of grain made in the fields that provided it (Dyer, 1989). Kent also traded internationally with the Low Countries, Gascoigne, Italy (Mate, 2010a). Trade was badly affected by contraction of the European economy in the 14th and 15th century due to the collapse of the population as well as the Hundred Year War (Mate, 2010b). As a result, guilds tended to tighten regulation to maximise income from tolls and fines, as well as reduce the number of apprentices in their trades (Kermode, 2000).

(iii) ***Ghent***

There was a large internal trade in Ghent, and this was partly aided by government influence. For example, Ghent forbade citizens to buy cloth made outside the town (Nicholas, 1992). As Flanders could not produce enough food for its population size from the 12th century onwards, it was therefore strongly dependent on international trade with its neighbours. Furthermore, increasing amounts of wool were imported from England, and in the 12th century Flemish merchants personally travelled to England to choose the finest wool. As a result, Flemish traders dominated sea trade with England across the Channel (Nicholas, 1992). This dominance was, however, lost in the 13th and 14th centuries due to war and the English crown requiring more control over trade (Nicholas, 1992; van Bavel, 2010). In the 14th century, England created a wool staple on the Continent – which it moved between Holland, Flanders and northern France according to political fluctuations at the time (van Bavel, 2010). Transport through the area was facilitated by extensive waterways and improvements to the road network. From the 12th century, a paved road lead from Cologne to Bruges going through Maastricht, Louvain and Ghent along the way (van Bavel, 2010). Furthermore, there was an increase in commercial places to stay overnight, such as wayside inns (van Bavel, 2010).

The Flemish trade was reliant on the relative peace in the larger countries surrounding it to be successful (Blockmans and Prevenier, 1999), but interruptions to trade were common (Nicholas, 1992). Furthermore, disruptions to international trade could fuel rebellions (Dumolyn and Haemers, 2005), but this was not one-sided. For example, England relied on good relations with Flanders for trade with Lombards, Germans and Brabanters (Nicholas, 1992).

3.6 The urban environment: Living conditions

The exponential growth of towns and cities puts strain on the existing infrastructure and may outpace the implementation of new infrastructure (Dahly and Adair, 2007). This is one of the main challenges faced by rapidly growing cities in the developing world today (e.g. Mumbai City, India Karn and Harada, 2002). However, providing a clean living and working environment and access to an adequate supply of potable water are essential for human health (Alirol et al., 2011; WHO, 2011). Contaminated water and unsanitary living conditions lead to an increase in a variety of diseases (e.g. diarrheal diseases) and the associated poor air quality leads to an increase in respiratory disease (Alirol et al., 2011). This section therefore reviews the archaeological and historical evidence on living conditions (buildings, water and waste management, personal hygiene and air quality) in late medieval towns.

3.6.1 Buildings and indoor living conditions

As time advanced a more “urban” type of domestic housing emerged. Buildings can be for domestic or public use. Public buildings would have taken up prominent positions within a town. They could have a commercial (e.g., guild hall), political (e.g., town hall) or symbolic (belfry) function (Stabel, 2000). Civic halls and guild halls became buildings were not only funded by a town council, but could also be funded by wealthy burghers or guilds (Haemers and Ryckbosch, 2010). Furthermore, cathedrals and churches still dominate the appearance of many European towns. However, the focus here will be on the domestic buildings.

The building material used for buildings determines the architectural possibilities. In late medieval NW European towns most buildings were erected in timber. This is even the case for Caen (Delente, 2000), where stone was abundant. However, wattle and daub, thatch, brick and stone were all used were all used as building materials (Schofield and Vince, 2005; Pearson, 2007; Rees Jones, 2008; Laleman and Vermeiren, 2010; Leguay, 2011). Sometimes buildings would incorporate part of the previous timber building, with stone buildings probably being developed over as much as 300 years (Schofield and Vince, 2005). The use of wood and thatch as building materials had the unfortunate consequence that house fires were common (Leguay, 2002b; Clark, 2009; Rawcliffe, 2013). The destruction of buildings could lead to destitution for the owners as residences and work spaces were destroyed (Leguay, 2002b). Moreover, the close proximity of buildings and the accumulation of organic waste in the street (see below) meant that fires could spread quickly and destroy entire quarters or even an entire settlement. Canterbury, for example, burned down entirely in 1161 and 1198 (Urry, 1967). These house fires would also lead to an increase in air pollution. Increasingly, towns introduced regulations to reduce the risk of fire: for instance, in the Low Countries from the 14th century, town rulers required the construction of houses in brick and tile (Nicholas, 1992). Not all houses would have been built entirely in brick. Fire safety required the foundations and side-walls to be built in brick (Bouwmeester, 2014). Furthermore, other precautions in Flanders included that all households were required to have a ladder, a bucket, and water nearby and chimneys were inspected regularly (Nicholas, 1992; Clark, 2009). Devastating as they were, such disasters could also have positive consequences as it provided opportunities for urban improvement and cleansed the site of accumulations of debris and natural and human waste (Clark, 2009).

No medieval timber houses remain standing in their entirety in these towns and the focus of archaeologists has therefore often been on extant stone buildings (Grenville, 1997, 2008; Pearson, 2007). These more durable buildings would have been reserved for the elite (Clark, 2009). As a result, the living conditions of the rich and poor would have varied dramatically (Riddy, 2008). In the 11th and 12th century, a spatial mixing of housing for the rich and poor was common in European towns. However, increasingly poverty was seen as a sin (see above), and housing became more segregated (Kermode, 2000; Stabel, 2000; Clark, 2009). In 14th century Ghent, stone buildings were predominantly concentrated in the commercial centre, timber buildings would have been present in other areas of the town and the suburbs (Laleman and Raveschot, 1994). The relationship between excavated houses, with collapsed floors, and standing houses is poorly understood (Giles, 2011). Dendrochronology (tree-ring analysis) on timber beams from late medieval houses has been able to date many houses, but it has also shown that high quality wood for building was scarce in Flanders due to overexploitation and deforestation (Haneca, 2005; Haneca et al., 2009; Kaplan et al., 2009; Sechi et al., 2010).

The size and lay-out of the houses varied from one or two room timber cottages to multiple storey stone or brick houses with a variety of rooms (Biddle, 1968; Rees Jones, 2008). This is not to say that wooden houses were always small. Evidence from the Netherlands shows great variation in their size (Safartij, 1990). Before the 14th century, the size of dwellings decreased to accommodate population growth i.e. more houses were built in the space available than would have been in previous periods when population numbers were lower (Nicholas, 1992; Grenville, 1997; Verhulst, 1999; Rees Jones, 2008). Furthermore, there was an increase in vertical building in comparison to rural areas (Laleman and Raveschot, 1994). Larger houses in towns were sometimes subdivided into sub-units which were let out separately (Schofield and Vince, 2005; Giles, 2011), thus increasing the population density. The size of the houses did, however, not only serves a functional purpose, but would also have a symbolic meaning. In Ghent, for example, the stone houses were bigger than would have been required for the demand on space (Laleman and Raveschot, 1994). After the Black Death (1348-1349), some houses in NW Europe appear to have become more spacious as the population density, and thus the demand on space, decreased (Britnell, 2000; Schofield and Vince, 2005). In Caen, many houses in the 14th and 15th century are described as having a garden (Angers, 2006). Houses may have been kept reasonably clean (Cipolla, 1992). Insect evidence from Hull suggests floors were swept regularly (Kenward, 2009).

Many domestic dwellings also functioned as a workshop and/or shop (Schofield and Vince, 2005). Historic evidence shows that the dwellings owned by Christ Church in Canterbury were mostly rented out for commercial and residential use (Duggan, 2010). In small houses this meant that rooms were used for multiple functions. In larger buildings there would be less pressure on the space and different rooms would have had different functions (Schofield and Vince, 2005). The distinction between the work and living environment would not have been as clear as it is in Europe today. By the 13th century many European towns would contain buildings dedicated to retail and storage (Schofield and Vince, 2005). By the 15th century, a distinction between dwelling and shop emerged in Flanders (Goldberg, 2001), and in England (e.g., Canterbury), houses without chimneys or other sources of heating have been discovered and these have been interpreted as shops (Urry, 1967; Pearson, 2007; Mate, 2010a).

3.6.2 Water

Water and waterways were an essential part of medieval urban life. Water was not only necessary for consumption, food preparation and cleaning, but also for certain industries and for putting out the regular house fires. Furthermore, the waterways were an important source of power for watermills and extensively used for transport (Van Leeuwen, 2005; Rawcliffe, 2013). Not all water was considered of equal quality and contaminated water was suspected as a cause of illness. Without today's scientific knowledge, the quality of the water was gauged from sensory perceptions (Magnusson, 2001; Ciecieznski, 2013). Common water sources included rivers, lakes, wells, fountains and rainwater and complex hydrological systems developed to bring water to town centres (Magnusson, 2001; Leguay, 2002a).

Rivers and streams were the easiest source of water for medieval towns and therefore used extensively. First, waterways were commonly used for transport and travel as the road network between towns could be poor quality and dangerous (Leguay, 2002a; van Bavel, 2010). They were also used as a source of power for mills. These mills were common in both urban and rural waterways and could impede navigation (Hoffmann, 1996; Leguay, 2002a). Furthermore, they played a major part in waste management for many towns (see below), and were often contaminated. In France, many rivers became known as *merderons* or *pissote* (Leguay, 2002a, 2011). For example, O'Connor (2004) has shown that York's river system was contaminated from the 10th century onwards, and fresh water fish species requiring large amounts of oxygen (barbel, burbot, and grayling) declined in York's water system during the 10th century and disappeared entirely in the 11th century (O'Connor, 2004). Urban dwellers therefore preferred other sources of water for daily use (Magnusson, 2001; Rawcliffe, 2013). However, as town councils struggled to provide an adequate supply of water through other sources, river water was still used (Magnusson, 2001). In some towns, alluvial deposits or wooden piers would allow people to collect water from the middle of rivers, which would be less polluted than the muddy water from the river edges (Leguay, 2002a).

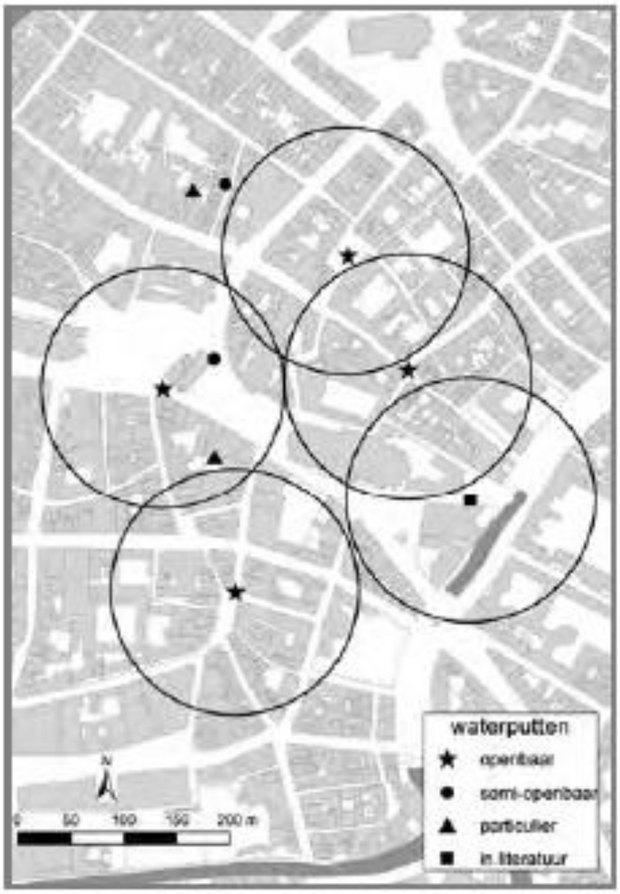
Wells could also be dug to make use of ground water as a source of potable water (Leguay, 2002a; Van Leeuwen, 2005). The sandy subsoil in Ghent meant this was an easy source of water in the town (Van Houtryve, 2013). However, this was not possible in all towns and complex water systems were developed to relay water from reliable sources outside the town walls (Magnusson, 2001; Leguay, 2002a; Van Leeuwen, 2005) These systems had three main components: an intake system at the source, a conveyance system and a distribution system within the town or religious house (Magnusson, 2001). The development of such a system could be an extended and expensive process (Magnusson, 2001). First, an appropriate source (a spring or lake) had to be located, and a route had to be designed between the source and the town centre. As the systems tended to be gravity based, this could mean that another source was required. When a route was possible, an uninterrupted conveyance system was needed between the source and the town centre. As not all land was owned by those creating the system, permission of land owners was necessary to lay pipes across their land. Some landlords would refuse, while others required an access point or monetary or spiritual recompense (Magnusson, 2001; Leguay, 2002a), and there could be one or multiple access points within the urban settlement. In Canterbury, the development of a water system for Christ Church took 14 years to complete (1153-67) (Magnusson, 2001). In NW Europe, these systems often developed first in religious institutions, and some towns opted to extend these religious systems to all urban citizens, while others opting to create parallel systems. Funding normally came from a combination of public and private sources (Magnusson, 2001; Rawcliffe, 2013), but many systems fell into disrepair due to inadequate funding (Magnusson, 2001).

As these systems were developed as a source of better-quality water, avoiding contamination was an important challenge. The water source itself could be contaminated, and sometimes protective structures were built around the source to avoid contamination (Magnusson, 2001). Conveyance could be in open canals or closed pipes in lead, ceramic or wood. Lead is toxic to humans and its use affects the nervous system, behaviour, and can lead to anaemia (WHO, 1993). Open canals would again expose the water to contamination, while closed systems provided better protection (Magnusson, 2001; Rawcliffe, 2013). Contamination at the access point was dependent on appropriate use by citizens (Geltner, 2012). Using the wells for doing laundry, for industry, or allowing animals to drink from it, could all contaminate the water and render it useless for consumption (Magnusson, 2001; Geltner, 2012). Regulations to limit certain behaviours or some industries from using the wells were quickly implemented, and some towns would even employ guards to enforce appropriate behaviour (Magnusson, 2001). Fountains and wells were popular when implemented and demand often outstripped supply. Town councils therefore developed restrictions in the use of the fountains, and regular householders would often get priority over industrial users. Sometimes industries would be temporarily banned from using the fountains altogether (Magnusson, 2001; Leguay, 2002a).

Towards the end of the late medieval period, many more complex systems were developed. However, the demand for more water would have compromised its quality, which had been so paramount in the previous centuries, with contaminated river water being used to supply the new systems (Magnusson, 2001). In France and Flanders, rainwater dripping from sloping roofs was also collected and preferred to river water (Leguay, 2002a; Van Leeuwen, 2005). This water was considered pure because it came “from the air” (Leguay, 2002a). However, this water would contain chemical impurities (e.g. heavy metals like lead) and pathogens from air pollution, and contamination from roof tiles and the systems used to catch and store the water (de Kwaadsteniet et al., 2013). In conjunction with the arrival of conveyance systems for clean drinking water, drainage systems for waste water emerged (Magnusson, 2001; Van Leeuwen, 2005). While closed piping was common for delivering water, open channels were common for drainage. Furthermore, the water systems often had a secondary source of lower-quality water for the drainage systems as quantity was more important than quality for drainage (Magnusson, 2001). This is discussed in more detail below

A complex water system was present in Christ Church, Canterbury with at least one access point for the general public (Magnusson, 2001). It is, however, unclear if access points would have been available throughout the town. Little is known about Ghent’s potable water supply (Laleman and Vermeiren, 2010; Van Houtryve, 2013), but no complex water system was installed and numerous wells giving access to ground water were the most common source of potable water. Figure 3.5 shows the dense distribution of known late medieval wells, some were publicly accessible, while other were private (Laleman and Vermeiren, 2010). Caen did have some water works in the 11th and 12th century, but this may not have provided an adequate supply to the entire population. The use of water which would now considered unfit for consumption is therefore likely to have been common in all three towns, and waterborne diseases may therefore have been common in all three towns.

Figure 3.5: Known late medieval wells in central Ghent with their estimated range of use. (star: public, circle: semi-public, triangle: private, square: literature) (Laleman and Vermeiren 2010, 29).



3.6.3 Waste management

In late medieval NW European rural areas animal and human waste were used as fertilisers. In urban areas, where population density increased and, as the economy was less based on agriculture, the need for fertiliser declined, surplus waste became a real problem (Jørgensen, 2010a; Bayless, 2012). The use of human and animal waste did, however, not disappear completely. Even in 18th century Edinburgh, night soil was used as fertiliser in the surrounding parishes (Davidson et al 2006).

Waste came from a variety of sources, including household waste, human and animal dung, and waste from construction and other industries (Leguay, 1999; Jørgensen, 2010b). Industrial waste has already been discussed in section 3.5.2 above.

Domestic waste was dumped in the street, river or even a neighbour’s yard (Jørgensen, 2010a; Bayless, 2012). Waste left in the street rarely drained away entirely, and the parts that remained would rot and putrefy in the street, creating a health hazard (Lentacker et al., 1997; Jørgensen, 2010a). Most towns therefore prohibited disposing of waste in the street (Jørgensen, 2010a). For example, an Ordinance in Périgueux (France) in 1342 forbade people to empty chamber pots outside the window (Leguay, 2011). A lot of the waste would directly or indirectly end up in the waterways and could impede other uses of the river (see above). In shallow or slow-moving rivers this could even lead to blockages (Leguay 1999). Every town therefore developed their own strategies and regulations to deal with waste disposal in waterways. York, for example, prohibited waste disposal in the river and Norwich redesigned its street system so that street runoff would not end up in the river (Jørgensen, 2010b). Furthermore, citizens in some towns had to assist in periodic cleaning of the waterways.

By the 13th century, many towns were also pro-active about regulating waste disposal (Jørgensen, 2008, 2010b, 2014; Clark, 2009). How successful these regulations were and therefore how much waste there would have been in the streets, is still debated (Guillerme, 1988; Zupko and Laures, 1996; Jørgensen, 2010b, 2014; Leguay, 2011; Bayless, 2012; Ciecieznski, 2013). Furthermore, not all towns were proactive about waste management. Namur (Belgium), for example, did not organise systematic waste collection as late as the 15th century (Lentacker et al., 1997). Areas within and around the settlement were demarcated for the disposal of waste and public and private latrines emerged. Designated waste disposal locations included ditches, moats or special rubbish heaps around the town perimeters (Jørgensen, 2010a). As a result, many ditches in France became known as *Merderon, Merdron* or *Merdançon* (Bayless, 2012). However, many may not have made the effort to use these areas and still disposed of waste in the street, or just outside the town gates (Jørgensen, 2010a). Having waste heaps outside towns did not solve all the issues; by the 17th century outside Paris they were so large that they needed to be incorporated in the city's fortifications lest they would be used by enemies as gun emplacements (Bayless, 2012). In many places householders were responsible for keeping the street in front of their house clean (Jørgensen, 2010a). This usually applied to an area the width of the house and up to the gutter in the middle of the street. In some towns waste collection services also emerged, where people were employed to remove waste from the streets or from the town centre, or to enforce the regulations (Jørgensen, 2008, 2010a). However, this may not always have been effective and many workers may have disposed of waste at the earliest convenience, for example on unused land (Leguay, 2002a).

Latrines can be described as seats above cesspits or running water such as rivers and streams (Jørgensen, 2010b; Bayless, 2012; Ciecieznski, 2013). High status houses might have had a private latrine, and neighbours sometimes shared the costs

(Rawcliffe, 2013), but many people would only have had access to public latrines. However, public latrines were not distributed equally across a settlement and thus not everyone had access to them (Jørgensen, 2010b; Bayless, 2012). Furthermore, public latrines in large French towns have been described as dirty and poorly used (Leguay, 2011). Furthermore, some people may have been reluctant to use public latrines as they were commonly associated with prostitution in the minds of the population (Bayless, 2012). Defaecation in open areas would therefore still have taken place. In the 15th century, there was a French law that stated that all new houses needed to have a privy (latrine), but as this did not apply to existing houses, the problems persisted in subsequent centuries (Leguay, 2002a).

Cesspits are likely one of the most commonly found archaeological features in urban medieval contexts (Smith, 2013). As they contain human as well as a wide variety of domestic waste, they contain animal bone, plant remains, insects, parasites as well as ceramic, glass and leather. The study of these elements can provide insights in diet, waste disposal, health and hygiene, as well as settlement history (de Clercq et al., 2007; De Groote et al., 2008; Smith, 2013). For example, a high prevalence of whipworm, fish tapeworm and roundworm in a latrine from 14th century Riga (Latvia) has been used as evidence of poor hygiene at the site (Yeh et al., 2014). These parasites can lead to B12 deficiency anaemia (Garcia, 2009). Furthermore, Mitchell et al (2011) have shown that in some cases, parasites could be used to show migration (see section 3.2 above). The contents of a reredorter (i.e. latrine) from St. John's hospital in Canterbury are discussed in relation to the diet in section 3.7 below.

Figure 3.6: Medieval wood-studded latrine pit from Greifswald (Scholknn, 2011)

Animal and human urine and dung were not only seen as waste, but could be used in certain industries. Dung was used in the manufacture of saltpetre, tanning leather and curing hides, and some urban dwellers collected it privately to sell as fertiliser (Bayless, 2012). In some areas, it may also have been used as a detergent for laundry (Bayless, 2012). Vessels for the storage of urine have been identified on archaeological sites (Schofield and Vince, 2005), some French dyers put barrels outside their premises to collect urine (Friedrichs, 1995). In addition to using these waste products, Industries and crafts created large quantities of waste and they were often tightly regulated (see section 3.5.2 above).

Little information is available on the waste removal services in Caen, Canterbury and Ghent. However, regular complaints in Canterbury in the 15th century regarding the state of the streets suggests that waste was not collected effectively (Rawcliffe, 2013). Furthermore, encroachments on the town's ditches were common (Sweetingburgh, 2010a). In Caen, any funds available would have been invested in defences in the 14th and 15th century as a consequence of the Hundred Year War (Leguay, 2002b; Gauthiez, 2010), and it is therefore unlikely waste removal services would have been common.

3.6.4 Personal hygiene

Personal hygiene was generally poor during the late medieval period (Howe, 1997; Magnusson, 2001; Leguay, 2002a). The frequency of laundry and bathing cannot easily be quantified, and may have shown considerable variation between the social groups and individuals, but it does not appear to have been a priority (Magnusson, 2001). Bathhouses were present throughout Europe and may have been used by some groups of the population, but they were also associated with prostitution (Smith, 2007). Improvements towards the end of the period have, however, been suggested (Magnusson, 2001; Leguay, 2002a). A lack of personal hygiene would have been ideal for fleas and lice, especially in thicker items of clothing (Behringer, 2010). Furthermore, ectoparasites are commonly found in archaeological material and confirm the lack of personal hygiene (Carrott et al., 1994; Bouchet et al., 2003; De Groote et al., 2008; Kenward, 2009; King and Henderson, 2013; Ponel et al., 2014).

3.6.5 Air quality

Air quality in the urban environment will have depended on a variety of factors including fuel use industry, and waste management in a settlement. Fuel has already been mentioned in regards to industry above. Wood, peat, organic matter and coal would all have been used as sources of fuel at this time (Nicholas, 1992; van Bavel, 2010; Rawcliffe, 2013). In Flanders wood was scarce due to overexploitation and deforestation (Haneca, 2005; Kaplan et al., 2009), and therefore wood was regularly imported from Kent (Galloway, 2001) along with peat in great quantities (Nicholas, 1992; van Bavel, 2010).

Indoor air pollution in residences would not only depend on the type of fuel used, but also on the level of ventilation in the building, including the efficacy of a chimney when present (Leguay, 2011). The elite would have lived in better ventilated, spacious houses and may have used better quality fuel than the poor. As a consequence, the houses of the poor were smokier than those of the elite (Leguay, 2011; Rawcliffe, 2013).

There is no specific archaeological/historical evidence for air pollution in Caen, Canterbury and Ghent. As there was a lack of differentiation between residence and workshop (see above), not only the workers, but other members in the household would also have been affected by industrial pollution, and there may therefore not be a significant difference in respiratory disease between males and females.

3.7 Diet and food availability

One of the characteristics of an urban settlement is that it has to rely on food imports to sustain its population. In the previous section it has already been shown that the economy of Ghent became strongly involved with the grain trade. This section reviews the variety of food available in late medieval towns and its accessibility in the population. In modern populations urban settlements tend to have a wider variety of food available, but the poorest may not be able to afford the variety available. The diet in NW Europe was broadly similar as it was based on Christian restrictions. Nevertheless there would have been noticeable regional differences (Woolgar, 2006). For example, Flanders was known for its consumption of dairy (milk, butter and cheese, eggs) (Adamson, 2004).

Archaeological and historical evidence shows that a variety of foodstuffs would have been consumed in late medieval towns, including a variety of meats, vegetables, legumes etc. Analysis of the biological remains of a 15th century reredorter form St. John's hospital in Canterbury has shown a great variety of foodstuffs including plant foods (e.g. plum, cherry, sloe, blackberry, raspberry, elderberry, strawberry, apple, fig), nuts (walnut and hazel), herbs, spices, wheat and a variety of animal and fish bones (Carrott et al., 1994). Towns also had best access to imported foodstuffs (Lilley, 2002). For example, Flemish merchants imported red and white herrings and saffron into Kent (Mate, 2010b). Furthermore, it has shown that both in northern France and England the sheep and cattle being slaughtered and butchered were mature in the 13th and 14th centuries, and that the age of these animals decreased in the 15th and 16th centuries, suggesting they were reared specifically for the dietary needs of the urban population in these later centuries (Banegas López, 2010). This shows that a wide variety of foodstuffs would have been available, but there would have been great variability in access to these products based on social status as well as sex and age. The elite are well-known for their dietary excesses in the late medieval period. Some products would not have been available to the middle classes, and even less to the poor. The diet of the poor may have strongly depended on (coarse) bread and broth, with occasional inclusion of meat. It is likely the diet of the poor was similar for Canterbury, Caen and Ghent (Adamson, 2004). In a study of Trino Vercellese, Northern Italy (8th–13th centuries AD), Reitsema and Vercellotti (Reitsema and Vercellotti, 2012) found differences in dietary isotopes between males and females, and similar differences may be present in NW Europe.

The poor did not have cooking facilities. However, in large towns in England (e.g. London, Canterbury) and France (e.g. Paris), they would have been able to buy ready-made hot meals from commercial cooks from at least the 12th century (Carlin, 1998). The food on offer in this manner in the 13th century was quite diverse and included: waffles, pastries, wafers, boiled and roasted meats (beef, veal, mutton, pork, lamb, kid, pigeon, capon, goose), prepared vegetables and legumes (e.g. hot mashed peas), spiced pasties and tarts (Carlin, 1995). Furthermore, people could have their own meat prepared by these commercial cooks (Carlin, 1995). These cooks did, however, have a reputation for dishonesty and uncleanliness (Carlin, 1995, 1998).

Dietary differences between the elite, the clergy and the poor have been demonstrated repeatedly in European medieval populations through stable isotope analysis (Polet and Katzenberg, 2003; Reitsema and Vercellotti, 2012). Pigière et al (2004) have also demonstrated this from the analysis of animal bones in various cesspits in Namur (Belgium). The diet of the poor in England and France would have been similar and mainly based on grain and pulses (Adamson, 2004; Dyer, 2006). However, the French would have been more likely to drink wine, while the English would have drunk ale (Adamson, 2004). Not much is known about the Flemish medieval diet, but dairy (milk, butter and cheese, eggs) played a significant role. Furthermore, meat and fish as well as bread were consumed in great quantities (Adamson, 2004). Barrett et al (2011) have shown that sea fishing in the North Sea increased from the 10th century onwards. While the fish bones in the 10th century were mostly from local fresh water sources, the quantity of sea fish increased over the subsequent centuries. This has been attributed to the rise of Christian dietary restrictions and an increase in the urban population. However, rich and rural areas would still have been consuming locally sourced fish (Barrett et al., 2011). This increase in marine food has also been found in carbon and nitrogen stable isotope evidence from archaeological human remains in York (Müldner and Richards, 2007). In addition, the presence of parasites associated with raw and undercooked meat have only been found in association with rich households (Rocha et al., 2006).

Famine was a regular occurrence, even in times of relative prosperity. In Flanders in the 12th century, there were 8 years of famine (Nicholas, 1992). However, crop failure was more common when the climate became less predictable in the 14th century. The Great Famine (1315-1317) lasted up to eight years in certain parts of Europe, and in Flanders this led to a change in crops grown, with an increase in peas and beans (Nicholas, 1992; van Bavel, 2010).

Urban farming, growing crops and raising livestock within city walls, was common in medieval towns. Townspeople would have used their gardens for growing crops and rearing pigs, chickens, and goats (Leguay, 2011). Chapter 2 has shown that keeping animals in this way can lead to outbreaks of disease (e.g. cholera) in modern populations (Battersby and Marshak, 2013). The overall poor sanitary conditions in late medieval towns (see section 3.6), suggests this type of disease may have been common. In addition to the urban farming taking place within town centres, many towns had common grazing lands outside the city walls (Kermode, 2000; Pearson, 2007). However, this would have been insufficient to supply enough food to the urban population (Kermode, 2000). Carbon and nitrogen stable isotope analysis of pigs from medieval York, for example, shows that the majority of pigs were fed a diet more likely to be found in rural circumstances (Hammond and O'Connor, 2013). Towns were therefore reliant on the countryside and trade from further afield to ensure adequate food supplies (Lilley, 2002), and this food supply was tightly organised and regulated (Kermode, 2000).

The hinterland of Caen and Canterbury would have supplied them with sufficient cereal crops in good harvest years. In Canterbury, urban dwellers were required to do "evework", which has been described as seasonal agricultural work (Urry, 1967). By the 13th century, many citizens paid a financial contribution to avoid doing the work, but poor women are still known to have done the work in the 16th century (Urry, 1967). Furthermore, in Caen the bourgeoisie created livestock contracts with local farmers. The former provided the animals, which were raised by the latter for years, with equal division of the profits when the animal was sold (Jouet, 1981a). Flemish agriculture, on the other hand, had insufficient yields to sustain its population from the 12th century onwards and therefore had to rely on imports from Germany and France (Nicholas, 1992). As Ghent had control over the Flemish supply through the grain staple (see section 1.5 above), the price of cereals would have been more stable than in other Flemish towns (Howell and Boone, 1996). Archaeological evidence from urban sites as far apart as the north of England and the south of France has shown that crops would have been infested with pests (Kenward, 2009; Ponel et al., 2014), and Kenward (2009) has identified an increase in grain pests with periods of increased urbanisation.

3.8 Migration

The reasons for migration in the past may have been as varied as they are today. First, people would have been moving in search of work (Grenville, 2008; Gerrard and Petley, 2013). This includes skilled labourers who wanted to progress (Stabel, 2004). However, poorer migrants may have been channelled from smaller to larger towns (Galloway, 2001; Hamelink, 2008). Another cause for migration would be to avoid disease, and people may have been displaced due to flooding or other catastrophes (Leguay, 2002a). Long-distance migration also included international merchants, who would have been travelling longer distances to and from trading centres (Clark, 2009). Furthermore, many pilgrims would have been on the roads out of piety or as punishment (Webb, 2004). Last, but not least, war could lead to migration. For example, in the 12th and 13th century many soldiers from Europe travelled to the Middle East to fight crusades (Mitchell and Millard, 2009; Mitchell et al., 2011), but many wars were also fought within Europe (e.g. many English soldiers were present in Normandy during the Hundred Year War) (Ormrod, 1994). Many people also fled from towns affected by war, and they may have been replaced by people seeking refuge from the hinterland (Jouet, 1981a; Leguay, 2002b).

Until recently, urban centres needed immigration to maintain or increase their population size as a result of increased mortality in urban areas (Woods, 2003; van Bavel, 2010). In the late medieval period the majority of immigrants would derive from a town’s hinterland (Galloway, 2007; Hamelink, 2008; Blockmans, 2010). Stable isotope analysis has previously been used successfully to identify long distance migration (Budd et al., 2004; Mitchell and Millard, 2009), but as stable isotope values are similar in large areas, they cannot be used to identify this small-scale rural-urban migration that was common in late medieval Europe (Pollard and Heron, 2008). Mitchell has also successfully used palaeoparasitology to identify long distance migration in the Middle East. The fish tapeworm (*Diphyllobothrium latum*) was common in Northern Europe, but not in the Middle East. Its presence in a 13th century latrine in Acre (Israel), can therefore be associated with the European crusaders (Mitchell et al., 2011). Roberts et al (2013) used stable isotopes to investigate the role of migration in the spread of treponemal disease in 14th-16th century Hull (England). They found that four of the six skeletons with lesions linked to treponemal disease had dental strontium and oxygen stable isotope signatures associated with the local environment and were therefore locally born and raised. The presence of treponemal disease could therefore not clearly be linked to a migrant population. It is, however, not clear if the individuals acquired the disease locally or external to the UK as Hull was an important international trading centre and if the individuals were sailors, they may have acquired the disease abroad or locally (Roberts et al., 2013).

The different patterns of migration would have impacted differently on Caen, Canterbury, and Ghent. Canterbury likely had the largest group of migrants; between the 12th and 15th century, pilgrims came from all around Europe to visit the shrine of St. Thomas (Duggan, 2010; Gelin, 2010). Furthermore, it was on the trade route between London to the North Sea coast (Gelin, 2010). In the 14th century, Canterbury introduced a fee for foreign traders to trade within Canterbury (Sweetingburgh, 2010a). Ghent was one of the largest towns in medieval Flanders and would therefore have attracted economic migrants, and the economy of Ghent was focused on local and international trade (Nicholas, 1992). Moreover, there were strong links between its urban and rural industry and there was a continuous movement between the town and its hinterland (Nicholas, 1992). However, despite the need for immigration to sustain population levels, Flemish towns would sometimes close their gates to migrants in the 14th-15th century (van Bavel, 2011). At the start of this period, Caen was prosperous and would have been trading internationally. However, over the centuries its international influence dwindled. Furthermore, it is known that the Hundred Year war and the arrival of the plague led to large-scale emigration from Caen (Angers, 2006), but immigration to Caen from the 14th century onwards may have been more related to warfare as the local rural population sought refuge from marauding soldiers (Angers, 2006).

3.9 Conclusion

In order to compare health in NW Europe, the previous chapter (Chapter 2) had identified factors affecting health in populations today. This chapter has discussed those themes in relation to Caen, Canterbury and Ghent in the late medieval period based on previous historical and archaeological research.

At the start of this period the climate was reasonably warm and stable (Büntgen et al., 2011; Goosse et al., 2012). However, from the 14th century onwards the climate became less predictable, as a consequence there were more natural disasters and crop failures leading to an increase in famines, with the Great Famine lasting several years (Leguay, 2002b; Galloway, 2009; Mouhot, 2013). As a consequence the population was relatively weakened and the prevalence of disease and pestilences increased (McMichael, 2012). Unfortunately, it is not possible for any of the sites analysed in this research to distinguish the skeletons from before the 14th century from those who lived and died afterwards. Caen, Canterbury and Ghent all reached their peak population density in the 13th century. From the 14th century, the population density in towns decreased as a consequence of mortality crises associated with famine and pestilences (Angers, 2006; Clark, 2009; Rawcliffe, 2013).

One of the major challenges of late medieval towns in NW Europe was dealing with poverty. A large proportion of the population would have been affected by poverty at some point during their lives, either permanently or temporarily (Clark, 2009; Fontaine, 2013; Van Steensel, 2013). Poor relief was not organised systematically and may not have reached those most in need. However, there appear to have been more opportunities in Ghent. The St. Pieter parish was partially affluent and partially poor (Nicholas, 1987). It is therefore likely that poverty affected the results in this study. In Canterbury, the skeletons came from both a parish and St. John's hospital (Hicks and Hicks, 2001). The cemetery in Caen covered a large area of the town (Huard, 1925) and it is therefore likely that it covers a range of socio-economic statuses within the population. However, Normandy is often the location for fighting in the Hundred Year War and other disputes (Angers, 2006), which has a negative impact on the economy and thus the population of Caen.

A clean living and working environment are paramount for human health. Sanitary conditions in late medieval Caen, Canterbury and Ghent would not have been up to modern standard. Sanitary conditions in northern France had a poor reputation at the time (Leguay, 2002b, 2011), but there is no evidence of effective waste removal in Canterbury and Ghent either. The complex water system may not have provided an adequate supply for the population (Magnusson, 2001), but the wells in Ghent might (Laleman and Vermeiren, 2010). Does this lead to a noticeable difference in the prevalence of indicators of adaptation in Caen?

Ghent is by far the most industrial of the three towns, while Canterbury and Caen are predominantly market towns. Does the contrast in occupations between Canterbury and Caen on the one hand, and Ghent on the other lead to difference in the prevalence rate of skeletal indicators in these populations?

Air pollution in all three towns would have come from the use of biomass fuels for heating, cooking and industry and toxic gases escaping from putrefying waste in streets if not removed in time (Leguay, 2011; King and Henderson, 2013). Especially the use of coal from the 13th century onwards would have had a negative impact on the air quality in these three towns (Keene, 2012). However, the air quality will have varied even within each settlement as the most polluting industries would have moved to the suburbs (Rawcliffe, 2013). The suburban and industrial nature of Ghent St. Pieter is therefore expected to have had a negative impact on the health of its population.

The majority of migration in the late medieval period would have been short-distance rural to urban movement. However, people would also have moved between towns and international trade was common. Canterbury's economy was focused on pilgrims and travellers between London and the Continent (Duggan, 2010; Gelin, 2010). As such, it is likely to have had higher levels of migration than Ghent or Caen. While Caen had an international reputation at the start of this period, by the 14th century it became predominantly a local distribution centre. However, English soldiers will have been prominently present in the region during the Hundred Year War (Angers, 2006). Ghent was an international trading centre (Nicholas, 1992; van Bavel, 2010). Migration is an important factor in the spread today and would have been so in the past (Alirol et al., 2011). However, it is not possible to identify migrants in the skeletons analysed in this research.

These themes will be revisited in Chapter 6 where the results (Chapter 5) of this research are interpreted. However, the next chapter will explore in more detail the three towns investigated in this thesis and the skeletal lesions that were used to explore the themes described in this chapter.

4.1 Introduction

So far this thesis has shown that rapidly developing cities today tend to have a negative impact on the health of their inhabitants (see Chapter 2) and that it is likely to have been the case for the expanding towns of late medieval NW Europe (see Chapter 3). This chapter describes in detail the sites from Caen, Canterbury and Ghent that are compared in this research. For each site a brief history of the town is included as well as details about the excavation and the skeletons selected.

Chapter 2 has also shown that bioarchaeological studies can contribute to our understanding of the socio-economic status, sanitary conditions and air quality of past urban populations. The second half of this chapter therefore describes the data that has been collected from the skeletons described in the first half of the chapter, the methods used and the analyses undertaken. The results from this study are then presented in the next chapter.

4.2 Materials

In order to compare health in NW Europe, skeletal assemblages from Caen, Canterbury and Ghent were analysed. This section provides a brief history of each town as well as details of the excavation and the skeletons incorporated in this research. Due to time constraints not all skeletons could be analysed from each site and a maximum of 100 skeletons was included from each site. The skeletons for this research were selected based on the following criteria:

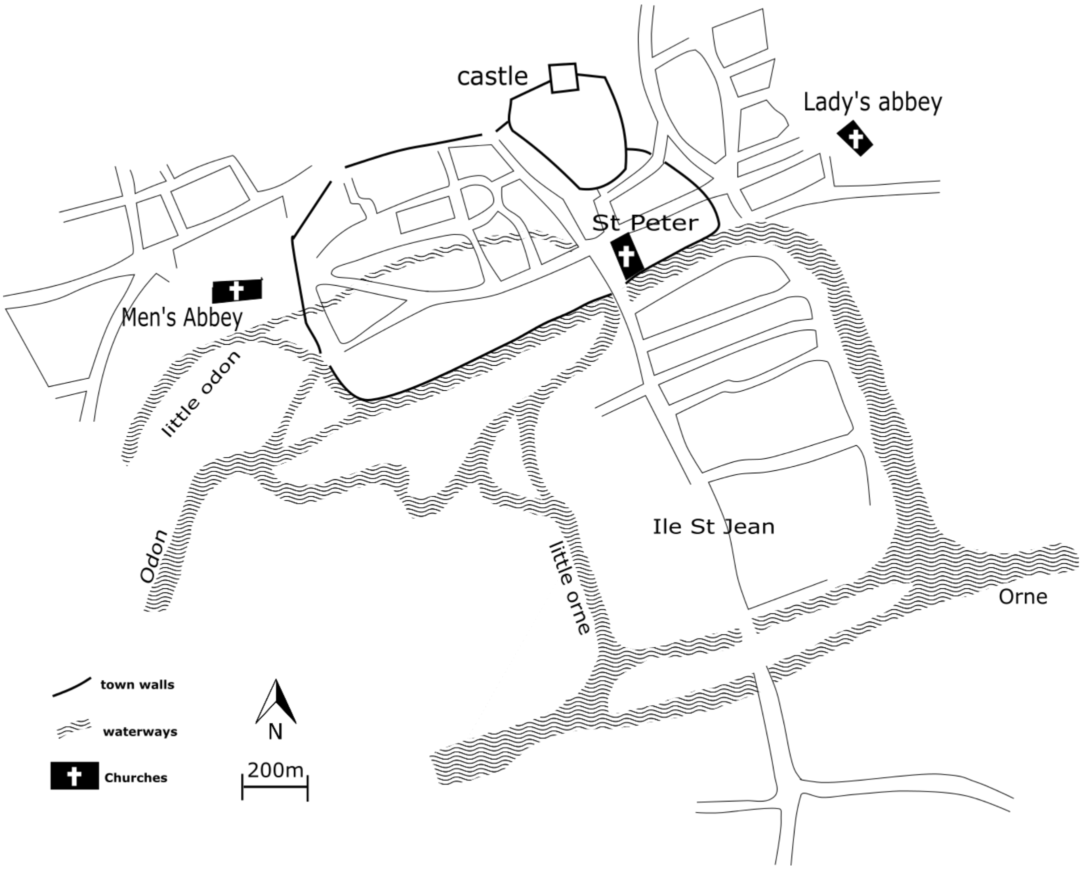
- **Adults**: this study only included adult remains to limit the bias that could be introduced by demographic differences between the populations.
- **Preservation**: the best preserved skeletons were selected for this study as it allowed the recording of the most skeletal indicators. In Ghent all adult skeletons which were sufficiently preserved were included (83 individuals), while in Caen and Canterbury a hundred skeletons were selected from much larger collections (see below for details)
- **Distribution across the site:** subsections of the population may be grouped within one part of the cemetery (Waldron, 1994); therefore an attempt was made to make sure the skeletons were distributed across the cemetery. However, this data was, however, not available from Canterbury and in Ghent all sufficiently preserved skeletons were included.

- **Sex**: some indicators have a male or female bias (see Chapter 2), to limit the bias, the same male/female ratio was used in all sites. Ghent was the first site analysed and was therefore the guideline for male/female ratio for Caen and Canterbury.

4.2.1 Caen

Caen is a town in the coastal region of Normandy in the north of France. It is located less than 20km from the coast on the confluence of the rivers Orne and Odon. The site under consideration here, Square Darnétal, is located in the city centre; just south of the castle and adjacent to Saint Peter's church (see Figure 4.1).

Figure 4.1: Outline of Caen's city centre in the 13th century (after Musset 1981a, 57)



(i) ***A brief history***

The history of Caen has its origins in prehistory (de Boüard, 1981), but it can be argued that its history really commences in the 11th century AD when it became favoured by the Norman dukes. The efforts of Duke William II of Normandy - better known as William the Conqueror - are pivotal (Musset, 1981a). He started the construction of the castle and two abbeys: *L'abbaye des hommes* (The Men's Abbey) and *L'abbaye des dames* (the Lady's Abbey). These three areas would form individual boroughs around which the town developed (Musset, 1981a).

William the Conqueror was not only the duke of Normandy, but also became king of England (de Boüard, 1970; Grant, 2005). Throughout the 12th century Caen managed to increase its importance by making important tactical decisions in the political power struggles that emerged at the succession of each Anglo-Norman king. Thus, it became a judicial financial and administrative centre, and essentially the second capital in Normandy (Musset, 1981a). Early in the 13th century Normandy became annexed to the French crown (Musset, 1981b).

However, the late medieval prosperity was not to last. Caen was really not prepared for the Hundred Year War. Apart from the castle, the town's defences had not been very well maintained since their construction by William the Conqueror, leaving Caen open for attack. Throughout this war the region was also strongly affected by troops ravaging and looting the countryside (Delente, 2000). The plague then hit Caen hard in 1352 and pestilences would affect the town regularly over the next few centuries (Jouet, 1981a). Apart from the high number of deaths, there was also the problem that part of Caen's bourgeoisie escaped to the relatively safe Brittany. As a consequence, the population, which had been estimated at above 10,000 inhabitants in the 13th century, dropped to likely under 7000 people (Jouet, 1981a). Some argue that the decline may not have been as significant because people from the countryside would have moved into the fortified city centre to escape the raids of bands of soldiers (Delente, 2000). However, the taxes were high and the poorer section of the population, which felt underrepresented by the nobility, sometimes rioted (Jouet, 1981a), the power and wealth of the town being in the hands of a few tens of families (Jouet, 1981a). During this period Caen largely lost its international status although it maintained a strong hold on its hinterland (Jouet, 1981a).

In the 16th century, stability returned to the region and the town started to grow again. Nevertheless, it was not the exponential growth seen in the 11th century. Despite the issues with finding comparable data throughout history (Jouet, 1981b), the population size of Caen at the end of the 16th century was estimated at 12,000 to 13,000 inhabitants (Jouet, 1981b). Its growth was in essence due to immigration from the surrounding countryside (Jouet, 1981b). Having lost most of its independence in the preceding centuries, Caen could not compete with Rouen in trade or power, despite being the only town in the region with a university (Jouet, 1981b). By the 16^{th} century, Caen's only international export is largely reduced to that of the local stone (Dujardin, 2010).

(ii) ***St Pierre de Darnétal***

The *Saint Pierre de Darnétal* (Saint Peter of Darnétal) parish in Caen is located in the centre of the town at the merging point of the rivers Orne and Odon - currently canalised. To avoid confusion with St Peter's parish in Ghent it will be further described as Darnétal (Leroux, 1997). Darnétal was one of the villages that were absorbed when Caen was awarded "borough"-status in the 11th century (Decaëns, 1997). It was known as *Saint-Pierre-de-Darnétal,* hereafter it is shortened to 'Saint Pierre' (Leroux, 1997). The Darnétal parish recorded 200 deaths per year around 1780, when other parishes were recording 75 deaths per year (Huard, 1925). There is less direct evidence for the rest of the period, but it seems that the Darnétal parish was the largest of the town throughout the medieval period and may have at times even represented up to a quarter of the Caen population (Huard, 1925).

The first written evidence for burial on the site comes from the 13th century , but it is believed that there was an earlier church on the same site with a licence to bury (Leroux, 1997). The cemetery consisted of two parts, one extending south of St Peter's church and one extending north (Leroux, 1997). The southern part was closed in the 15th century as a result of land-exchange between the church and the town council. A new cemetery was started a little out of town. However, as the north part remained in use, this was much more popular with the parishioners and the new cemetery was discontinued in the 17th century (Leroux, 1997). The north cemetery remained in use until in the 18th century when a law was passed which prohibited burial within the town due its unsanitary conditions (Neveux, 1981b; Leroux, 1997)

(iii) ***Excavation and skeleton selection***

Square Darnétal was excavated prior to modern building development in the area. First, a trial trench was excavated in July 1990. This was then followed by a more extensive excavation in 1991 organised by the archaeological unit of the Musée de Basse-Normandie (Museum of Lower-Normandy) under the direction of Pascal Leroux. The area excavated was 350m^2 in size and included the north cemetery, part of a neighbouring medieval fish shop, and evidence of early medieval occupation. Disturbance of the site was limited to a few trenches related to the Second World War (1939-1945) (Marin et al., 1991; Leroux, 1997).

During the excavation details of 900 skeletons were recorded and the great majority were recovered (Marin et al., 1991). Those that were recovered are currently curated at the Centre Michel de Bouard at the University of Caen Basse-Normandie and have not previously been studied. For this study, 100 adult skeletons were selected based on the criteria described above.

A typo-chronological study was the basis for the relative dating of the site and was part of a larger project to date the medieval cemeteries of Caen (Marin et al., 1991; Leroux, 1997). Despite reservations about the accuracy of the dating (Pers. Comm. Cécile Niel), the number of skeletons from each phase are given here:

Phase I (8th-11th century): indicates the first use of the cemetery. This part of the cemetery was too early in date for use in this study.

Phase II (12th – 14th century): Only 11 skeletons were recovered from this phase and all of them were included in this study.

Phase III (15th- 18th century): this category was most strongly represented with over 800 skeletons recorded. Fifty-seven skeletons came from this phase.

Phase IIIb (1474-18th century): the construction of the Last Judgement Portal in 1474 led to a change in burial direction from NW-SE to SW-NE, and could thus be distinguished in the cemetery. Thirty-two skeletons in this study came from this latest phase.

In this project, the results have not been divided into the phases described here. Instead they have all been attributed to the use of the cemetery (12th -18th century). A list with the phase attributed to each skeleton is provided in Appendix A.

4.2.2 Canterbury

Canterbury is a town in Kent in the south-east of England located between London and the English Channel Coast (See Figure 4.2). This section provides a brief history of Canterbury and St. Gregory’s priory as well as describes the excavation and skeletons used in this research.

Figure 4.2: The location of Canterbury within England

(i) ***A brief history***

The oldest settlement of present-day Canterbury dates to the Iron Age (Méar-Coulstock, 2010). During the Roman period, Canterbury was a small town which was promoted to a civitas capital (Méar-Coulstock, 2010). In the 6th century AD, it became the first Episcopal See in Britain and has retained its religious power through the centuries (Méar-Coulstock, 2010). The urban landscape of Canterbury was more comparable to the north of France and Flanders than to similar-sized towns in England. It had a relatively small, but densely populated hinterland (Keene, 2000; Galloway, 2007).

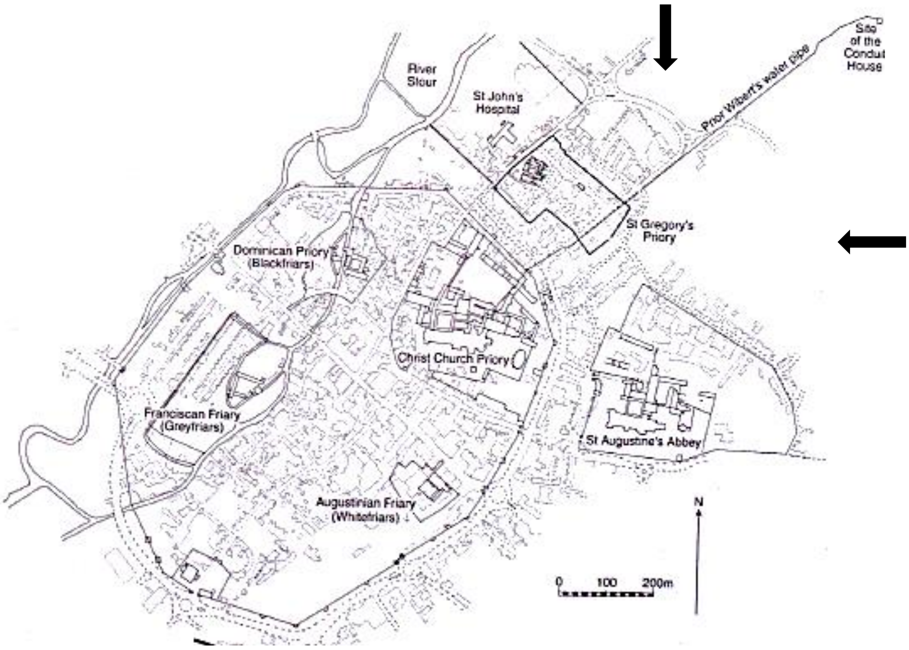
In the 12th century Canterbury was one of the four main towns in the south-east of England, together with London, Winchester and Oxford and had a population estimate of about 6000 inhabitants (Keene, 2000). The town was dominated by the two monastic houses: Christ Church and St. Augustine (Gelin, 2010). However, the murder of St. Thomas Beckett in the cathedral in 1170 very quickly led to the formation of a cult (Duggan, 2010). As a result, Canterbury became an important place of pilgrimage within Europe for the next three centuries (Lincoln, 1955; Webb, 2004).

Canterbury was badly affected by the plague of 1348-49 and mortality crises were occurred repeatedly throughout the next century (Méar-Coulstock, 2010; Rawcliffe, 2013). After the decline of its population in the 14th and 15th century due to the plague, it started to grow again towards the end of the 16th century (Bower, 2004). The pilgrimage came to a dramatic end in 1538 when the shrine of St. Thomas was destroyed (Webb, 2004; Duggan, 2010), and its economy of Canterbury was badly affected by the disappearance of the pilgrims (Duggan, 2010).

(ii) ***St Gregory's priory and the Northgate parish***

A church was founded in the 1080s to serve the spiritual needs of the hospital of St. John across the road (see Figure 4.3) (Tatton-Brown, 1995). In 1133 the church became an Augustian priory (Hicks and Hicks, 2001). The clergy of the priory had a pastoral duty of care which included ministering to the sick, performing baptisms, hearing confessions and providing burial for the poor (Hicks and Hicks, 2001). The priory also quickly acquired the church of St. Mary 'over the Northgate', as well as the churches of Holy Cross and St Dunstan around the Westgate; the cemetery would therefore have ministered to many parishioners in Canterbury until after the Dissolution in the 16th century (Tatton-Brown, 1995). Throughout its time, St Gregory's wealth was modest (Hicks and Hicks, 2001). The inmates from St John were still receiving burial in the 1530s (Sparks, 2001), but the priory was dissolved in 1536 (Sparks, 2001). After dissolution, the prior's house became private property and the church was levelled to form part of an ornamental garden (Hicks and Hicks, 2001). In addition, St Gregory's was used as a legal centre by the archbishop of Canterbury and kept its archives and treasury (Sparks, 2001).

Figure 4.3: Proximity of St. John's hospital and St. Gregory's priory (Hicks and Hicks, 2001: 27)



(iii) ***Excavation and skeleton selection***

The site was excavated in 1988 and 1991 by Canterbury Archaeological Trust prior to development of the site (Hicks and Hicks, 2001). The excavation revealed part of the priory buildings as well as burials from the church, priory and cemetery of St. Gregory's, as shown in Figures 4.4 and 4.5 (Hicks and Hicks, 2001). A total of 1342 articulated skeletons were excavated from the cemetery, church and priory of St. Gregory's (Anderson and Andrews, 2001). However, funding only covered the analysis of the 91 skeletons associated with the church and priory (Hicks and Hicks, 2001). No comprehensive study of the cemetery population has been undertaken. This project looks at a 100 skeletons from the cemetery population as indicated in blue on Figure 4.4 and Figure 4.5. Documentation relating to the cemetery and notes on the remaining skeletons by the late Trevor Anderson are not easily accessible as they have been distributed over different institutions (Alison Hicks, pers. Comm.) and thus no further detail can be provided regarding the location of the skeletons within the cemetery.

Figure 4.4: Location of the excavation (in blue and pink) in relation to Canterbury (with permission of Canterbury Archaeological Trust)

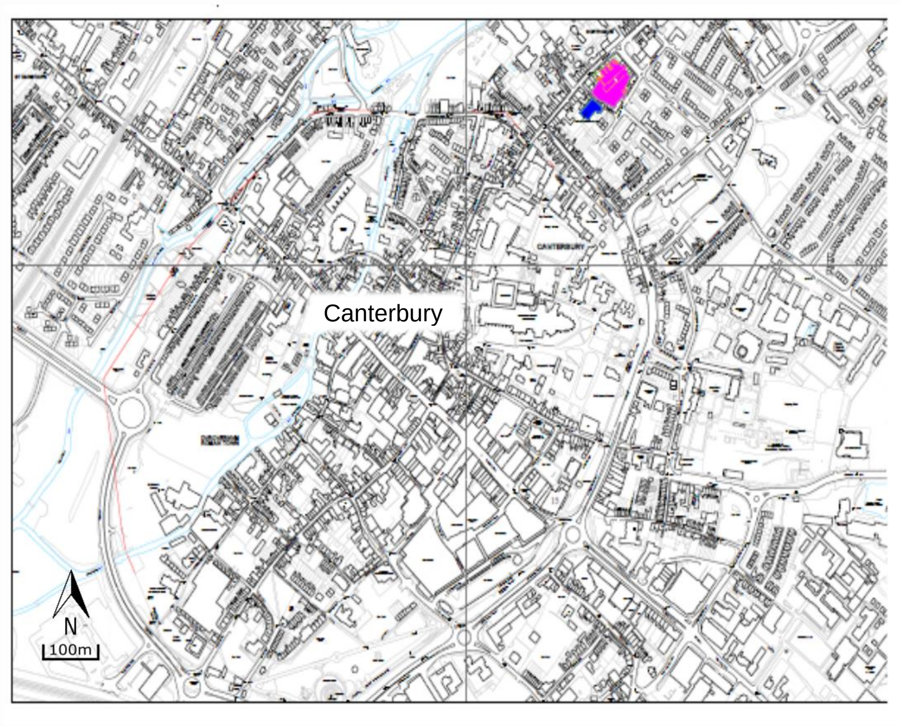
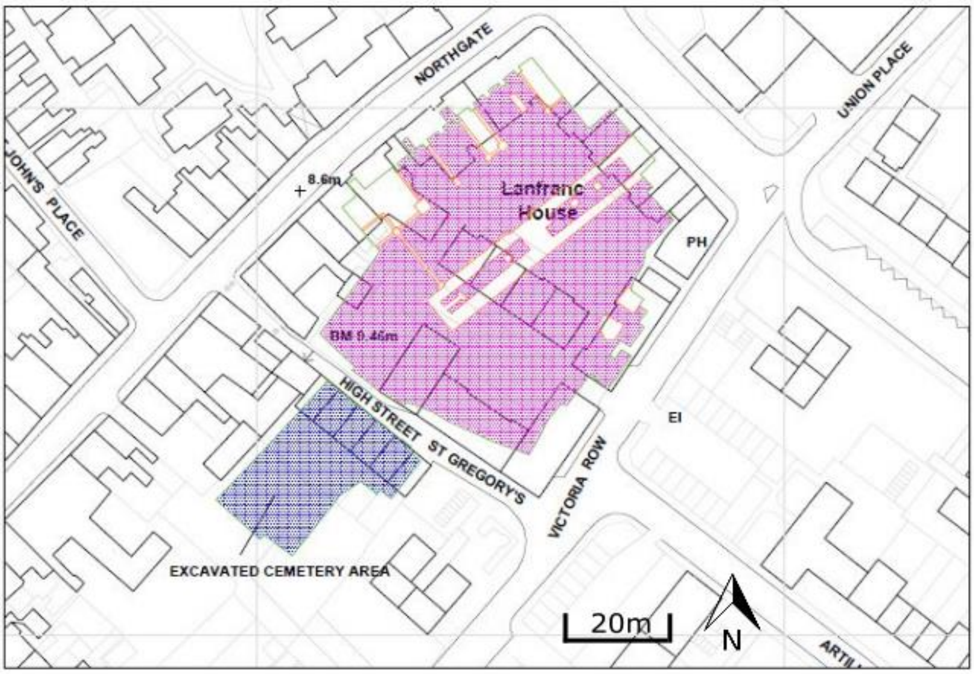


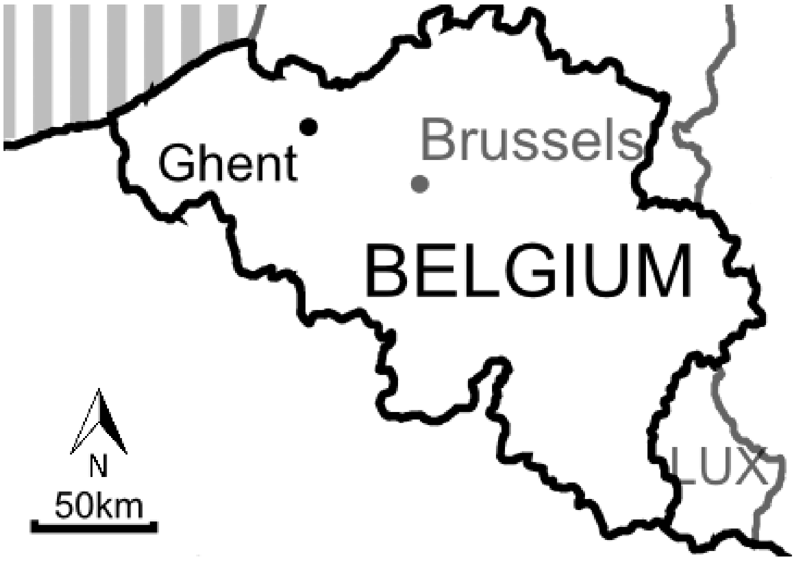
Figure 4.5: Map showing excavated area (with permission of Canterbury Archaeological Trust)



4.2.3 Ghent

Ghent is a town in current-day Belgium which is located on the confluence of the rivers Scheldt (*Schelde*) and Lys (*Leie*) (see Figure 4.6). The following section provides a history of the town, and the Sint Pieter parish, and describes the excavation and the skeletons that were selected for this research.

Figure 4.6: The location of Ghent within Belgium



(i) ***A brief history***

Archaeological evidence suggests that there has been a continuous settlement at the location of modern-day Ghent since prehistory (Laleman, 2008). However, it is only since the Norman invasions that Ghent developed into an urban centre (Laleman, 2008). By the 12th century Ghent was the largest town in Europe outside Italy, apart from Paris, and it gained political and legal status in 1128, giving it certain privileges. In the next few centuries, the town would aim to gain further privileges through negotiation or rebellion (Arnade, 1997; Boone, 2002; Dumolyn and Haemers, 2005).

The growth of Ghent continued into the 13th century. However, the appearance of Ghent changed dramatically. The town had grown organically so far, but now the street plan was redesigned to optimise the city centre for trade, with the creation of markets and guildhalls (Haemers and Ryckbosch, 2010). Furthermore, the city walls were expanded seven times in the 13th and 14th centuries (Laleman and Vermeiren, 2010). In addition, a certain area outside the city walls (a ban-mile) was subject to laws of the city (Nicholas, 1992).

As elsewhere in Europe, the 14th century troublesome (Clark, 2009). Wars, revolts, famines and epidemics lead to economic and population decline (Nicholas, 1992).The population has been estimated to drop from 50,000 in 1357 to 25,000 by 1385, but then grew by the 15th century (Nicholas, 1992). While other places in Europe were hardest hit by the first plague in 1349, Ghent (and the other Flemish towns) were actually affected more by the later episodes, especially that of 1368-69 (Nicholas, 1992; van Bavel, 2010).

In the 15th century, Ghent (and the other Flemish towns) saw the power they had held over the last few centuries disappear gradually as the Burgundian and Habsburg rulers centralised power (Arnade, 1997; Dumolyn, 2006). In 1540 Ghent was stripped of all its medieval privileges, both legal and political, as part of the Caroline Concession (Arnade, 2008), and this led to a reorganisation of the political and corporate elements of the town (Arnade, 2008).

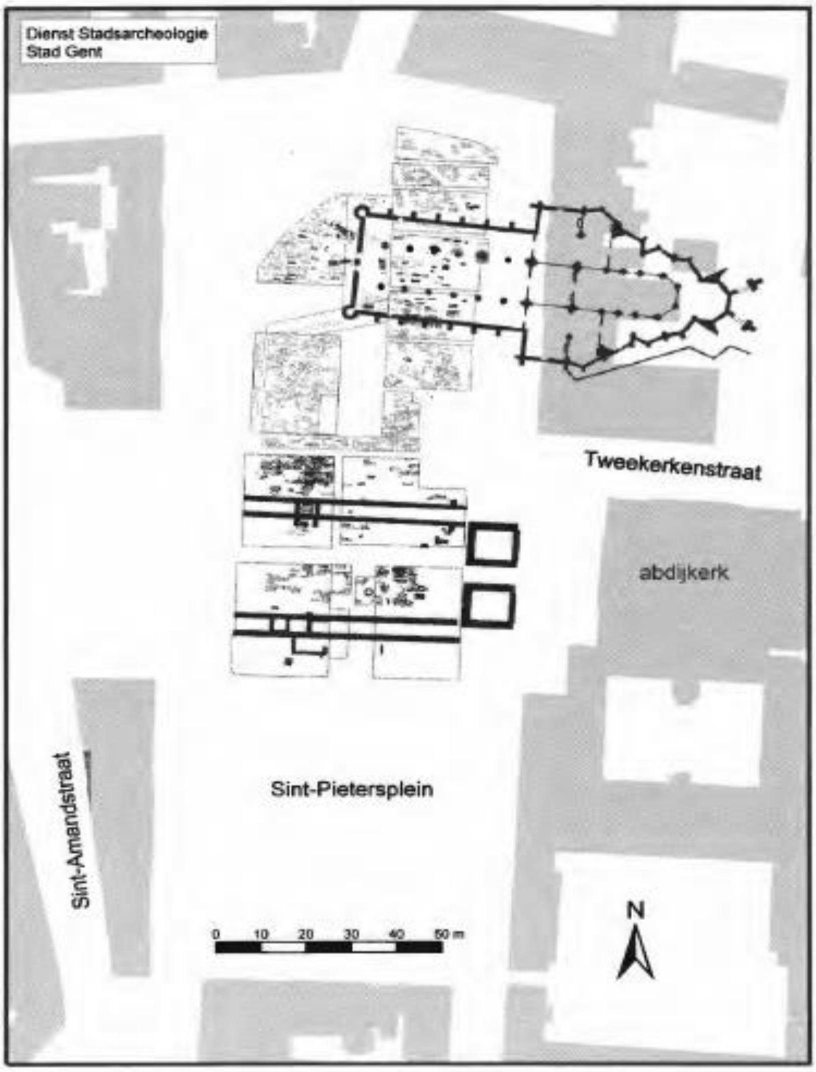
(ii) ***Sint Pieter parish***

The Sint Pieter parish (*Sint Pieterskwartier)* initially developed as a village around the Abbey of Sint Pieter. As the city grew, the parish was gradually incorporated, with one part incorporated in the 13th century, while the remainder was only incorporated in the 14th century (Nicholas, 1987; Van Houtryve, 2013). As it was located on the outskirts of the town it managed to maintain a more rural character until the 18th century (Nicholas, 1987; Van Houtryve, 2013).

(iii) ***Excavation and skeleton selection***

The Sint Pietersplein (St. Peter's place) in Ghent was excavated between 2002 and 2003 by *Dienst Archeologie, Stad Gent* in advance of development of the site (Van den Brempt and Vermeiren, 2004). This excavation revealed part of the Sint Pietersabdij (St. Peter's Abbey) and part of the parish church and cemetery of Sint Peter (Bru et al., 2010) (see Figure 4.7). The site was in use from the 12th to the 18th century. However, the uppermost layers of the site may have been removed when the area was levelled in the 19th century. The archaeologists believe only the medieval skeletons remain (Laleman pers. comm.).

Figure 4.7: Site plan of the Sint Pietersplein in Ghent (with permission of Dienst Stadsarcheologie stad Ghent) Abdijkerk is the abbey church



(iv) ***Skeletons***

For this study the skeletons from the church and graveyard from the Sint Peter parish were studied. Three hundred and twenty-four skeletons were recorded on site. Twenty-five of the initial 324 could not be found in storage. It is reasonable to assume that some of them may have been thrown away post-excavation due to poor preservation. If this was the case, this fact was not documented. A further 23 skeletons were non-adult and thus excluded from this study. Lastly, 126 were considered but not included as a result of poor preservation and comingling of multiple skeletons, which could not be distinguished from the information available. Taking into account all the omissions, a total of 83 adult skeletons were selected for this study.

4.3 Methods

For each of the sites described above, a range of indicators have been recorded to compare health in urban NW Europe. The following indicators of adaptation are used to infer living and working conditions in Caen, Canterbury and Ghent: dental enamel hypoplasia, non-specific periosteal reaction, cribra orbitalia and stature. Periosteal rib lesions and maxillary sinusitis were recorded as indicators of respiratory disease and therefore the air quality in these towns. As sex and age at death can have an impact on the prevalence of lesions, they have been recorded first and the demographic distribution has been presented for each lesion. Furthermore dental disease (caries and peri-apical lesions) were recorded to consider their possible impact on the presence of maxillary sinusitis. The skeletons were recorded according to standard methods published in the UK (Brickley and McKinley, 2004), but each method is described in detail below. The preservation of the relevant skeletal and dental elements was also recorded in order to calculate prevalence rates for the health indicators.

In the bioarchaeological literature, prevalence rates for specific diseases are often provided at the level of the number of individuals affected, regardless of the preservation of the skeleton. As this does not necessarily take into account issues with preservation, this has previously been described as a '**Crude prevalence rate'** (CPR) (Roberts and Cox, 2003). However, CPR are also calculated with reference to the preservation of the part of the skeleton of interest (e.g. the frequency rate of spines affected by osteoarthritis only focuses on takes the skeletons with spines preserved for observation). Quite often when CPRs are presented, it is unknown whether preservation has been taken into account (Roberts and Cox, 2003).

'**True prevalence rates'** (TPR), on the other hand, are calculated by dividing the number of preserved relevant bone elements or teeth/tooth sockets with a specific lesion by the number of times the element/tooth/tooth socket is affected in the sample (Roberts and Cox, 2003). For example, for the purposes of this study, the CPR of maxillary sinusitis would be the number of individuals with maxillary sinusitis as a proportion of those with the number of individuals with at least one sinus present for observation in the population (e.g. 50 individuals of 100 = 50%). However, maxillary sinusitis is not always bilateral and the frequency would therefore be an underestimate. The TPR would be calculated by counting the number of maxillary sinuses preserved for observation affected by sinusitis compared to the number observed (e.g. 100 observed and 50 affected = 50%). The result would be a much more accurate description of the prevalence of maxillary sinusitis in the population.

In this study both the CPR and TPR are provided. For the crude prevalence rate, only individuals were the indicator could be recorded were included in the calculation. For the true prevalence, the value is provided both for the number of teeth present as for each tooth category (incisor, canine, premolar, and molar).

All the data were initially recorded on a paper-based form and later entered into a specifically designed Microsoft Access 2010 database. Each skeleton was given a unique identification based on a three-letter abbreviation of the site name and the on-site identification number. The letter codes were as follows: DAR for Caen, NGA for Canterbury, and SPP for Ghent.

4.3.1 Demography

Demography is fundamental in interpreting skeletal indicators. The methods used to determine age-at-death and sex from the skeletons are described here.

(i) ***Sex determination***

Sex estimation of adult skeletons is based on a visual assessment of morphological traits that present as sexually dimorphic in humans. These traits only diverge between males and females during puberty as part of the biological process of sexual maturation (Stone et al., 1996; Mays and Cox, 2000; Scheuer and Black, 2000). In general, males have larger and more robust bones and teeth. Previous studies have shown that pelvic morphological traits most accurately reflect sex as they are less affected by environmental factors (Kelley, 1979; Meindl et al., 1985; MacLaughlin and Bruce, 1990; Sutherland and Suchey, 1991; Ubelaker and Volk, 2002). One limitation of methods used is that preservation can have a negative effect on their reliability as the most reliable indicators cannot be assessed (Meindl et al., 1985; Walker, 2005). Furthermore, the strength of sexual dimorphism is dependent on ethnicity (Mays and Cox, 2000). As this study focuses on NW Europe, the sex estimation methods developed for white European populations were applied.

Each trait observed for each skeleton was classified as female (F), possible female (?F), indeterminate (?), possible male (?M), male (M), and "not available or observable" i.e. not present because of poor preservation (N/A). As the skull and the innominate bones of the pelvic girdle do not always survive in archaeological contexts, morphological assessment was supplemented with long bone measurements. Details of the morphological and metrical assessments applied in this study are discussed below.

Pelvic morphology

Table 4.1 shows the morphological traits used in this research. Phenice's (1969) description of the morphological differences between male and female pubic bones have been estimated to be accurate for sex in 88% to 95% of cases (Sutherland and Suchey, 1991; Ubelaker and Volk, 2002), and MacLaughlin and Bruce (1990) found that in European populations the subpubic concavity was the most reliable sex indicator. However, in archaeological contexts, this part of the skeleton is fragile and often damaged or lost post mortem. Even small amounts of post-mortem damage can affect whether the pubic bones can be used for sex estimation (Kelley, 1979).

In terms of history of sex estimation using the pelvis, Phenice (1969) described three morphological features present on female pubic bones that were absent on male bones: the ventral arc, subpubic concavity and ischiopubic ramus ridge. In addition, the shape of the pubic bone and the subpubic angle have been described for both sexes. The general shape of the pubic bones have been documented as longer and broader in females and narrower and shorter in males when observed from their anterior aspects (Brothwell, 1981; Mays, 2010). The subpubic angle has also been described as 90° or greater in females (Brothwell, 1981). This refers to the length of the medial edge of the obturator foramen and the pubic symphyseal face and the width of the pubic symphysis from the proximal to distal edge (Brothwell, 1981; Mays, 2010). The greater sciatic notch has been noted to be wider in females and narrower in males. However, it has been shown that there is a bias towards females in the recording of this trait (Buikstra and Ubelaker, 1994; Walker, 2005), and that it is more susceptible to genetic variation, age-related changes, and disease than the sub-pubic concavity (Brothwell, 1981; Walker, 2005; White and Folkens, 2005). Apart from the previously described traits, the following characteristics were also recorded: the shape of the obturator foramen, which is triangular and smaller in females and larger and oval shaped in males (Brothwell, 1981), the acetabulum, which is larger in males than in females (Brothwell, 1981; White and Folkens, 2005), the shape of the sacrum, being relatively smaller with wider sacral segments in females and larger but narrower in males (White and Folkens, 2005), and the curvature of the sacrum, which is described as more gradual and continuous in females, with more dramatic changes in males after the third sacral segment (Brothwell, 1981).

Table 4.1: Pelvic characteristics used for sex estimation

Acetabulum shape	Pubic bone shape	Subpubic angle
Medial ischio-pubic ramus	Sacrum morphology	Subpubic concavity
Obturator foramen	Sciatic notch	Ventral arc

For this project, the standards methods recommended by Buikstra and Ubelaker (1994) and Brickley and McKinley (2004) have been followed. In France, a method using probabilistic sex diagnosis based on measurements of the hip bone (DSP) (Murail 2005) is more commonly used, but was not used here.

Skull morphology

Male skulls are generally larger and more robust than those of females in European populations (Brothwell, 1981; Meindl et al., 1985; Loth and Henneberg, 1996) and tests in documented (known age and sex) populations suggest an accuracy of sex estimation using the skull of around 80% (Brothwell, 1981; Meindl et al., 1985). Unfortunately, the robusticity of a skeleton is not only affected by biological sex, but is also influenced by genetics, health, environmental factors such as nutrition and workload, population growth and maturation rates (Wolfe and Gray, 1982; MacLaughlin and Bruce, 1990; Walrath et al., 2004). Cranial robusticity is age dependent and male characteristics are often not fully expressed until the individual is 30 years old (Walker, 1995; Walrath et al., 2004). Furthermore, post-menopausal women can develop these masculine traits, especially in the cranium (Walker, 1995). Table 4.2 shows the traits that have been recorded in this research.

Table 4.2: skull traits used for sex estimation

Supraorbital ridges	Bossing	Nuchal crest
Posterior zygomatic arch	Mastoid process	Mental eminence
Forehead	Orbital rims	Mandibular ramus flexure

First, the forehead in females is usually more vertical in profile, with the male forehead sloping backwards beyond and above the brow ridges (Brothwell, 1981). Bossing on the frontal and parietal bones is a female characteristic, but the skulls of young adult males can also cary this feature (Brothwell, 1981).The posterior root of the zygomatic process does not extend past the external auditory meatus in females, but is present as a well-defined ridge in males (Brothwell, 1981). Acsádi and Neméskeri (1970) described five more sex-based morphological differences based on robusticity. In males, the supraorbital ridges are more prominent, the upper margin of the orbit is more rounded, an occipital protuberance is present on the posterior aspect of the occipital bone (nuchal crest), and the mastoid processes are more developed (Brothwell, 1981). Some characteristics of the mandible are also more robust in males: the mental eminence is more pronounced (Acsádi and Nemeskéri, 1970; Brickley, 2004), and lateral gonial flare and flexure of the posterior border of the mandibular ramus may be present level with the occlusal surface of the dentition (Brothwell, 1981; Loth and Henneberg, 1996).The latter is, however affected by mechanical stress, disease and increasing age (Koski, 1996; Loth and Henneberg, 1996; Donnelly et al., 1998; Brickley, 2004).

Metrical assessment

The robusticity of a skeleton can also be determined via measurements of various bones of the skeleton (Parsons, 1915; Kelley, 1979; Brothwell, 1981; Bass, 1995). The following six post-cranial measurements were recorded according to Bass (1995):

- maximum length of the clavicle,
- the maximum width of the glenoid fossa,
- the diameter of the humeral head from the maximum proximal and maximum distal edges,
- the maximum diameter of the radial head,
- the maximum diameter of the femoral head,
- the femoral bicondylar width.

An osteometric board or sliding calipers were used to take these measurements to the nearest millimeter. The results were then compared with previously published metrical data for white European populations (see Table 4.3).

Table 4.3 Metrically based sex determination

Measurement	Female (mm)	Male (mm)	Reference
Clavicle max length	<138	>150	(Brothwell 1981)
Maximum width glenoid cavity	<26.1	>28.6	(Brothwell 1981)
Humerus head diameter	<43	>47	(Ubelaker, 1989)
Femur bicondylar width	<74	>76	(Bass 1995)
Femoral Head diameter	<43	>48	(Parsons, 1915)
Radial head diameter	<21	>23	(Ubelaker, 1989)

(ii) ***Age-at-Death Estimation***

The age-at-death estimation methods used in this study are based on degenerative processes observed in the skeleton (Cox, 2000). The following standard non-destructive methods were used and will be discussed in more detail below:

- pubic symphyseal degeneration (Brooks and Suchey, 1990)
- degeneration of the sternal rib end (İşcan et al., 1984, 1985)
- degeneration of the auricular surface on the innominate bone (Lovejoy et al., 1985)

Current methods have been criticized for overestimating the age of younger individuals and underestimating the age of older adults (Saunders et al., 1992; Molleson and Cox, 1993). These errors have been shown to decrease when several estimation methods are used in combination (Lovejoy et al., 1985; Bedford et al., 1993). As the age-ranges are method-specific, the results were grouped into four standard age categories for this study: young adult (<35), middle adult (35-50), old adult (>50), and a generic “adult” for those which could not be put in one of the previous categories because the relevant elements were not available for examination or because the results did not fall within one of the categories (Buikstra and Ubelaker, 1994, p 36). These age categories were used to calculate age specific pathological lesion prevalence rates and statures, and to test for variability in rates both within and between age groups (Connell, 2004).

Pubic Symphysis

The age-related changes to the pubic symphysis were first recognized in the 1920s (Todd, 1921a; b). Visual inspection of the pubic symphyseal face has become the most reliable age estimation method in adult skeletal remains; this is because the published descriptions are supplemented by industry-standard casts of each phase for males and females (Brooks, 1955; Lovejoy et al., 1985; Meindl et al., 1990; Saunders et al., 1992; Bedford et al., 1993). Unfortunately, the pubic bone is often damaged or lost in archaeological contexts (Cox, 2000). Another limitation is that the age ranges at the 95% interval become wider with each category (see Table 4.4).

Table 4.4: Pubic symphysis phases according to Brooks and Suchey (1990)

Female (95% range)	Phase	Male (95% range)
15-24	1	15-23
19-40	2	19-34
21-53	3	21-46
26-70	4	23-57
25-83	5	27-66
42-87	6	34-86

The Suchey-Brooks method (Brooks and Suchey, 1990) was used in this research to assess age related pubic symphysis morphology. The method was only applied after the sex of a skeleton had been estimated as the changes are sex-specific and the casts are divided into male and female (Suchey et al., 1979). Pubic symphyses from skeletons of indeterminate sex were compared to both the male and female casts and descriptions and the most representative phase from both cast sets was recorded for that individual.

Fourth Rib Sternal Ends

Morphological changes to the sternal ends of the fourth rib have been linked to age in white and black populations (İşcan et al., 1984, 1985). As it can be challenging to identify the 4^{th} rib in fragmentary archaeological skeletons, it has been shown that the method can be applied to other ribs centrally placed in the rib cage without significance loss of reliability (Loth et al., 1994; Yoder et al., 2001).

The sternal end of the fourth rib was visually compared with industry-standard casts (again male and female are separate sets of casts) and with the physical descriptions published by (İşcan et al., 1984, 1985). The method is again dependent on sex and therefore was applied after had been estimated. For skeletons with indeterminate sex, the rib was compared with both male and female casts. Table 4.5 shows the age ranges for the phases in this method.

Table 4.5: Age ranges for the 4th rib ageing method (İşcan et al., 1984, 1985)

Male age (years)	Phase	Female age (years)
<17	0	<14
17-19	1	14-15
20-23	2	16-19
24-28	3	20-24
26-32	4	24-32
33-42	5	33-46
43-55	6	43-58
54-64	7	59-71
>64	8	>69

Iliac Auricular Surface

The auricular surface of the innominate of the pelvis survives well in archaeological contexts and a method, and derivatives of, has been developed to estimate age from the auricular surface (Lovejoy et al., 1985; Buckberry and Chamberlain, 2002; Schmitt, 2002). The Lovejoy et al (1985) method was chosen for this project to maximise the numbers of skeletons which can be assigned an age category. The method is independent of sex, i.e. one method for both males and females (Cox, 2000). Furthermore, it does not rely on the presence of the pre-auricular surface, and which may often be damaged post mortem (Cox, 2000). The iliac auricular surface was visually compared with a series of photographs (Figure 5.11), complemented with descriptions, and assigned to one of the eight phases (see Table 4.6).

Figure 4.8: Photographs showing the age-related changes to the auricular surface (Lovejoy et al 1985 as reprinted in White and Folkens 2005, 382-3)

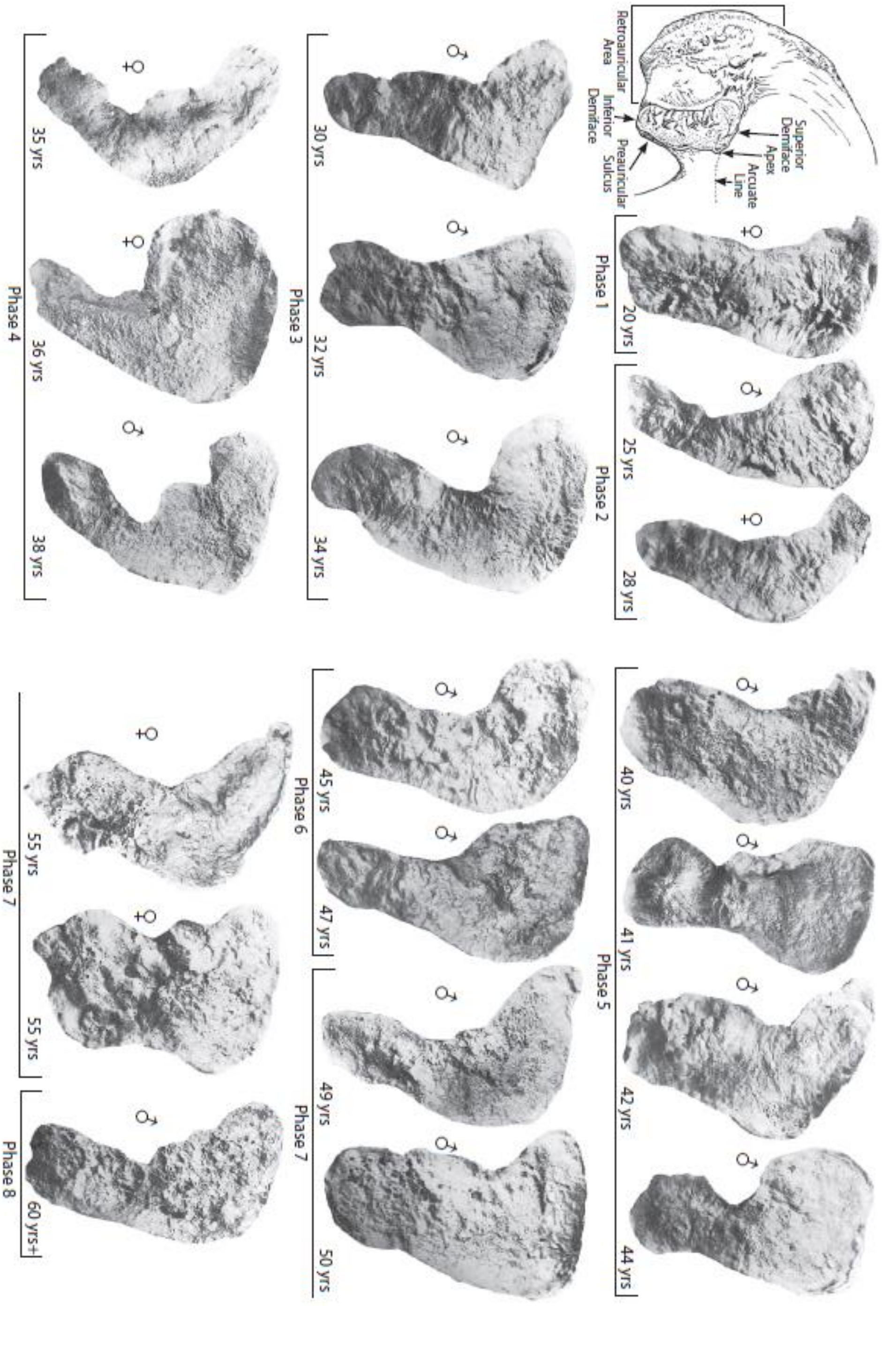


Table 4.6: Age ranges associated with degenerative changes of the auricular surface (Lovejoy et al 1985)

Phase	Age range (years)
1	20 – 24
2	25 – 29
3	30 – 34
4	35 – 39
5	40 – 44
6	45 – 49
7	50 – 59
8	60+

4.3.2 Dental disease

Dentitions from archaeological contexts are often incomplete. Furthermore, not all teeth will be affected by the same disease to the same extent. Dental disease was therefore recorded for each tooth individually. The FDI (*Federation Dentaire International*) Two-Digit Notation was used to inventory the teeth present and absent (see Table 4.7). The first digit indicates the quadrant of the tooth and the second digit which specific tooth (Harris, 2005). This is an extension of the recommended Zsygmundy system (see Table 4.8). As the Zsygmundy does not number the different quadrants, it is harder to digitise and thus use for analysis on a computer (Buikstra and Ubelaker, 1994; Connell, 2004; Harris, 2005). Table 4.9 shows the notations used for recording the dental inventory.

Table 4.7: FDI - two digit dental recording system

18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Table 4.8: Zsygmundy system for recording teeth

8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8

Table 4.9: Abbrevations used in dental inventory recording

Recorded	Meaning
present (P)	Tooth present
root (R)	Only the root of the tooth was present
not present (NP)	Tooth not present, but cause of absence could not be determined
post-mortem tooth loss (/)	Tooth not present, but the tooth socket shows no sign of remodelling.
ante-mortem tooth loss (x)	Tooth not present and the tooth socket shows signs of remodelling.

(i) ***Caries***

Caries is the progressive demineralisation of dental tissue (Hillson, 2005). It develops from a white or brown spot into a cavity and can appear on the crown, root or cervix of the tooth (Brothwell, 1981; Hillson, 2005; Wasterlain et al., 2009). Caries tend to occur more in the molars, and this can be attributed to their complex occlusal surface (Brothwell, 1981; Hillson, 2005).

In this study the presence or absence of caries lesions was recorded for every tooth individually. Caries lesions were only recorded as present when a clear cavity was present (Figure 4.9). The inclusion of brown/ white spots could be confused with diagenetic change and introduce inter-observer bias (Hillson, 2001, 2005). Prevalence rates were provided for the proportion of teeth present, per tooth category and the number of individuals affected in a population. For Ghent, only the presence or absence was recorded, in Caen and Canterbury the location on the tooth and the surface affected was also recorded.

Figure 4.9: Caries lesions in the right mandibular molars of skeleton NGA704

(ii) ***Periapical lesions***

Periapical lesions (Figure 4.10) are cavities in the bone of the mandible or maxilla related to the root apex (Ogden, 2008). They are caused by abscesses, cysts and granulomata (Hillson, 2005; Ogden, 2008). These lesions usually have rounded edges, but can be difficult to distinguish from post-mortem damage if they have not healed (Hillson, 2005). Furthermore, the majority of lesions may not be visible macroscopically as they are contained within the mandible or maxilla (Djurić and Rakočević, 2007). In this study, periapical lesions were recorded because of their potential to cause maxillary sinusitis. Therefore, only lesions in the maxilla were recorded (see Chapter 2 for an explanation). The maxilla was visually examined and lesions were recorded as present, absent or not observable in relation to the tooth they affected (Boldsen, 2005).

Figure 4.10: Periapical lesion in skeleton SPP 250

4.3.3 Indicators of adaptation

(i) ***Dental Enamel Hypoplasia (DEH)***

Dental enamel hypoplasias are defects of the tooth crown due to disruption during the formation of the enamel matrix (Hillson, 2005). The defects usually appear as pits or horizontal grooves and are most commonly found on the anterior teeth (Hillson and Bond, 1997; Hassett, 2013). Microscopic methods for identifying DEH identify more lesions than macroscopic methods (Hassett, 2013). However, this is time consuming and the tools required were not available for this study.

Each tooth was examined macroscopically. As a result, defects visible in the outer layer of the enamel were recorded (Palubeckaité et al., 2002). For each tooth lesions were recorded as present, absent or unobservable. When lesions were present a distinction was made between mild and severe lesions in order to distinguish those with repeated episodes. A lesion was described as mild when there was only one defect on a tooth. Multiple lesions on the same tooth were recorded as severe (Figure 4.11).

Figure 4.11: Severe DEH on a tooth from SPP531c

(ii) ***Non-specific Periosteal Reaction on the Tibiae***

Periosteal reaction represents an inflammatory response to a variety of conditions (see chapter 2). Some diseases can be identified through new bone formation/destruction distribution patterns representing specific infections, for example tuberculosis, leprosy and treponemal disease (Aufderheide and Rodríguez-Martín, 1998; Ortner, 2003; Roberts and Buikstra, 2003). The majority of lesions representing inflammatory bone changes can, however, not be linked to a specific disease or trauma (Weston, 2012).

Periosteal reaction was recorded systematically on the shafts of tibiae only as this captures the majority of non-specific periosteal reaction that occurs in archaeological skeletons (Weston, 2008). To record the extent and distribution of lesions, each tibia was divided into three segments, the proximal third, middle third, and distal third, and within these segments, any surfaces affected were recorded, whether the reaction was either focal or diffuse, and the type of bone formation present (woven, lamellar or mixed) as recommended (Ortner, 2003; Roberts and Connell, 2004; Weston, 2012) as shown in Figure 4.13 and 4.14. As the distribution of periosteal reaction is essential to its interpretation (Ortner, 2003; Weston, 2008, 2012), lesions were only recorded when both tibiae were preserved and could be observed. Unilateral, focal lesions are most often associated with trauma (Weston, 2012). On the other hand, bilateral lesions are interpreted as caused by a pathological condition (Klaus, 2014).

Figure 4.12: Example of woven bone formation (Ortner 2008: 197)

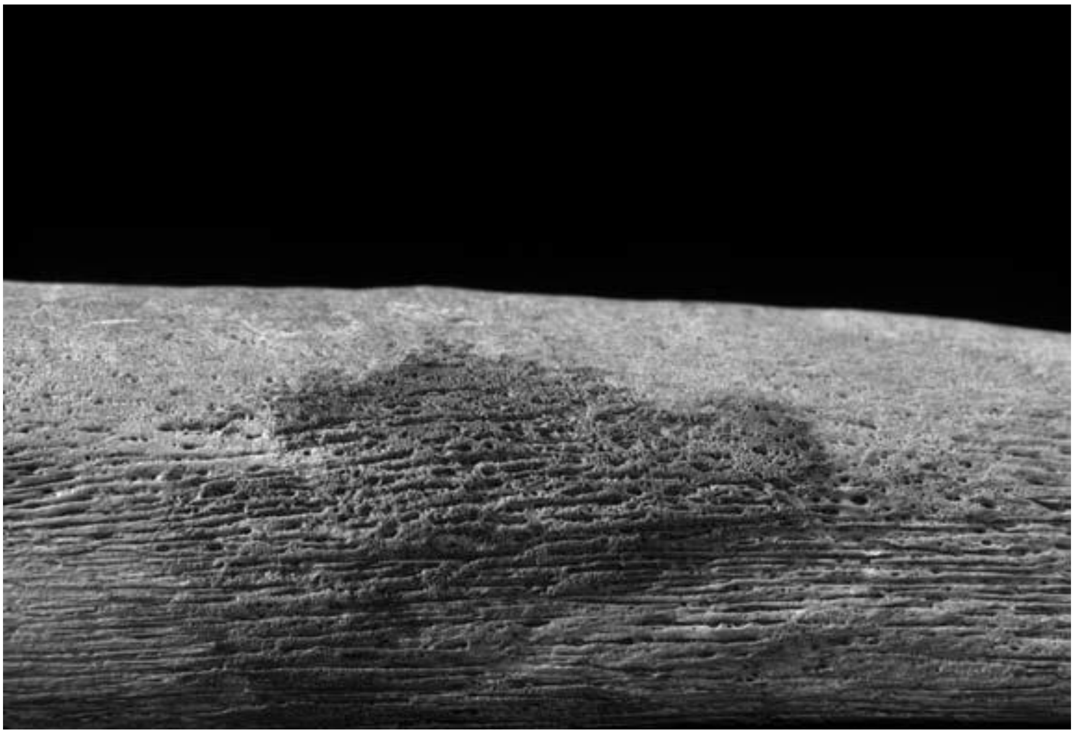


Figure 4.13: Example of lamellar bone formation on a tibia from skeleton NGA452

(iii) ***Cribra orbitalia***

Cribra orbitalia are lesions formed in the orbits as a result of expansion of the diplöe and normally occur symmetrically (Stuart-Macadam, 1985; Walker et al., 2009; Galea, 2013). Multiple scoring systems have been suggested (Mensforth et al., 1978; Stuart-Macadam, 1985), but it has been shown that the scoring of the orbits is strongly subject to inter-observer error (Jacobi and Danforth, 2002). Lesions were therefore recorded as present or absent for each orbit individually (see Figure 4.14).

Figure 4.14: Cribra orbitalia in the right orbit of skeleton NGA501

(iv) ***Stature***

Stature was calculated from long bone length based on the regression formulae for white men and women developed by Trotter (1970). The maximum length of long bones was measured to the nearest millimetre according to Bass (1995) using an osteometric board. Long bones from the left side were preferred when available as recommended in Buikstra and Ubelaker (1994). The long bone measurement with the smallest error range (see Table 4.10) was used to estimate stature and the results were rounded up to the nearest centimetre.

Table 4.10: Stature regression formulae for white males and females according to Trotter (1970)

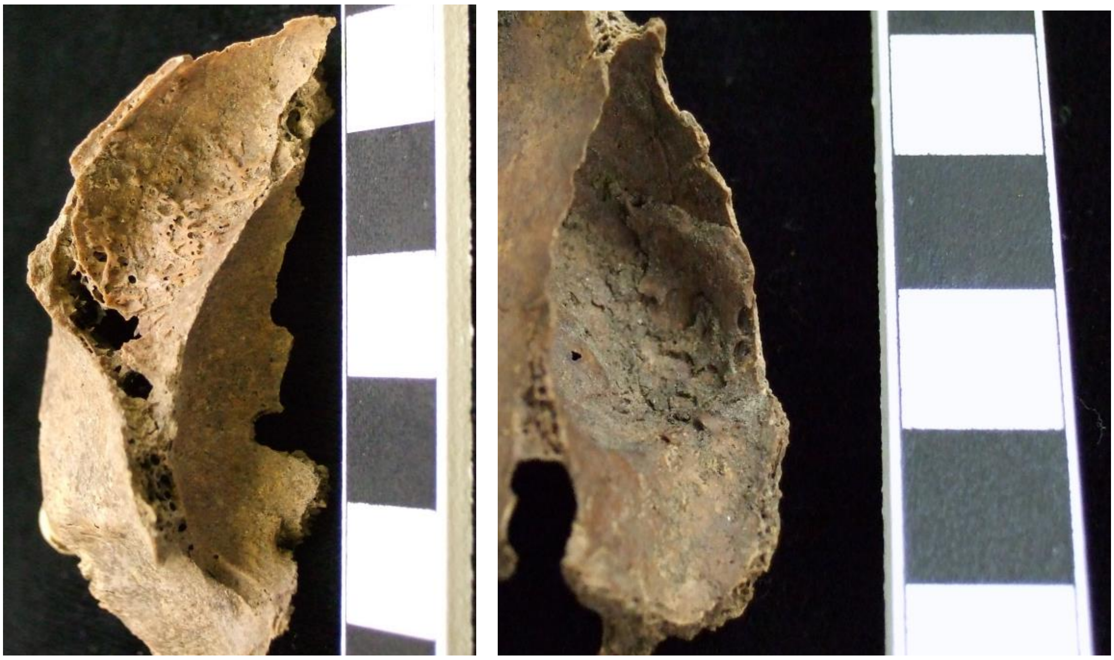
Sex	Formula					Error range
male	1.30	x	(femur+ tibia)	+	63.29	*2.99*
	2.38	x	Femur	+	61.41	*3.27*
	2.68	x	Fibula	+	71.78	*3.29*
	2.52	x	Tibia	+	78.62	*3.37*
	3.08	x	Humerus	+	70.45	*4.05*
	3.78	x	Radius	+	79.01	*4.32*
	3.70	x	ulna	+	74.05	*4.32*
Female	1.39	x	(Femur+ tibia)	+	53.2	*3.55*
	2.93	x	Fibula	+	59.61	*3.57*
	2.90	x	Tibia	+	61.53	*3.66*
	2.47	x	Femur	+	54.1	*3.72*
	3.36	x	Humerus	+	57.97	*4.24*
	4.74	x	Radius	+	54.93	*4.30*
	4.27	x	Ulna	+	57.67	*4.45*

4.3.4 Respiratory disease

(i) ***Maxillary sinusitis***

It is not possible to recognise the cause of maxillary sinusitis from the bone lesions as the bone changes are non-specific (Waldron, 2009). However, the following categories of bone changes have been recorded as maxillary sinusitis in British studies (Boocock et al., 1995; Lewis et al., 1995a; Roberts, 2007; Bernofsky, 2010): bone spicules, remodelled spicules forming a plaque of additional bone, pitting and white pitting (Figure 4.15).

Figure 4.15: Spicules in the maxillary sinus of NGA 1173 (left) and plaque formation in NGA 725 (right)



In this study the interior surface of each maxillary sinus was examined visually for signs of these lesions. The majority of sinuses were damaged post-mortem and could be analysed by the naked eye. When the sinus was more complete an endoscope (Rimmers Brothers, model number CLS150-2 with a 45 degrees Karl Storz attachment) was used in line with Bernofsky (2010). Maxillary sinusitis was recorded as present or absent.

Dental disease is a known cause for maxillary sinusitis (Boocock et al., 1995; Panhuysen et al., 1997; Roberts, 2007), and therefore prevalence rates for caries and periapical lesions were calculated (see above) and the prevalence of maxillary sinusitis of skeletons with and without dental disease were provided.

(ii) ***Periosteal Rib Lesions***

Ribs normally have a smooth visceral surface (Bernofsky, 2010). Pfeiffer (1991) described three types of lesions: additional bone growth on the ribs (see Figure 4.16), porous expansion of the cortex without distinct edges, and lytic lesions on the head and neck. In addition, Nicklisch et al (2012) have recently described a grading system for these lesions, but as this was published after the start of data collection in this project, this was not used.

Figure 4.16: Periosteal reaction on the visceral surface of a rib from NGA 542

The bioarchaeological literature shows that strong correlations have been found between rib lesions and tuberculosis (Pfeiffer, 1991; Roberts et al., 1994, 1998; Lambert, 2002; Santos and Roberts, 2006). However, biomolecular identification of tuberculosis in skeletons with rib lesions has yet to be successful (Mays et al., 2002; Nicklisch et al., 2012) and the lesions cannot be considered pathognomonic (Molto, 1990; Roberts et al., 1998; Mays et al., 2002; Santos and Roberts, 2006). In this research the lesions are therefore interpreted as non-specific evidence of respiratory disease.

An inventory of the ribs was created before recording the presence of abnormal bone changes. When possible, the ribs were assigned a side based on Mann (1993). Attempts were made to reconstruct fragmentary ribs but, due to time constraints, only a limited time could be devoted to reconstruction. Each rib or fragment was then examined for evidence of pathological changes. The type of additional bone growth (lamellar, woven, and mixed) was recorded for each rib. Trauma can also lead to periosteal reaction (see 4.3.3(ii)), but, as this project focused on respiratory disease, skeletons with evidence of trauma (fractures) to the ribs were excluded (Bernofsky, 2010).

4.3.5 Statistical Analysis

PAST software was used for statistical analyses (Hammer et al., 2001). The main statistical test used was the Chi-square test, used to test for significant differences in pathological prevalence rates between and within subgroups of populations as well as between the three populations. When counts for these variables were less than five, the Fisher's Exact Test was used instead to test for probable non-random relationships between variables. A T-test was conducted to compare stature calculations between the populations.

4.4 Conclusion

A total of 283 adults skeletons from the sites of the Darnétal parish cemetery in Caen (n=100), the cemetery of St. Gregory's priory in Canterbury (n=100) and the suburban cemetery of St. Pieter in Ghent (n=83) have been used in this project to explore and compare health across NW Europe. This chapter has provided the context for each of these sites and has described the various skeletal indicators used in this research. Indicators of adaptation (stature, cribra orbital, DEH and periosteal reaction) as well as respiratory diseases (maxillary sinusitis and periosteal rib lesions) are used to interpret sanitary conditions and air quality. The results of the analyses are described in the following chapter (Chapter 5) while the interpretation of these results in terms of health based on sanitary conditions and air quality can be found in Chapter 6.

5.1 Introduction

The previous chapter described the three sites, the methods used, and analyses undertaken in this research. This chapter describes the results of analyses before they are discussed in the next chapter. The results from each site are first presented individually, followed by a comparison between the sites. For each lesion recorded, the true and crude prevalence rates are provided (see section 4.3 for details). The raw data is available in Appendix B (on disc).

5.2 Caen

5.2.1 Demography

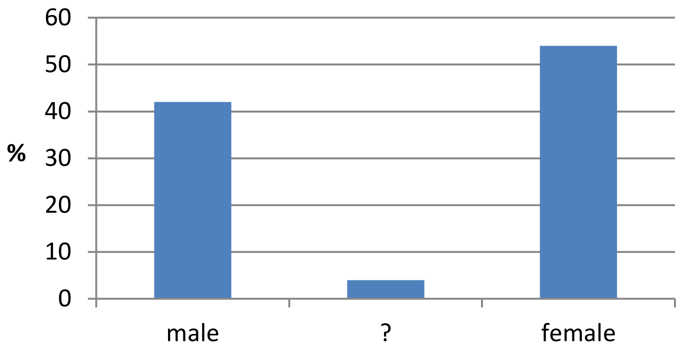
(i) ***Sex estimation***

Sex was estimated for all 100 skeletons and categorised as follows: definitely male (M), probably male (?M), sex unknown (?), probably female (?F) and definitely female (F) and the results are presented in Table 5.1. Figure 5.1 shows the distribution when male and probably male categories are combined as well as female and probably female combined to reduce the number of categories, and thus increase sample sizes per category when looking at lesions. This is here referred to as “simplified” sex distribution. Ninety-six individuals could be attributed to either the male or female categories and 56% (47/96) of those were female.

Table 5.1: Sex distribution in Caen

Sex	No.
M	26
?M	16
?	4
?F	27
F	27
Total	**100**

Figure 5.1: "Simplified" sex distribution in Caen

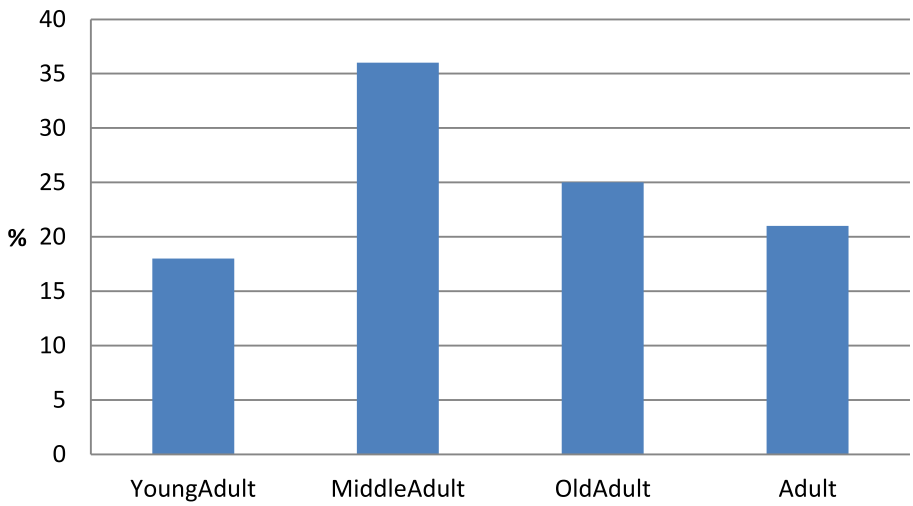


(ii) ***Age estimation***

Age categories

Only 21% (21/100) of the skeletons included in this project could not be assigned a specific age category and were grouped under a generic 'adult' category (see Figure 5.2). The middle adult age category (35-50) was best represented in this sample population (36/100), followed by the older age category (25/100) and lastly the young adult (18/100).

Figure 5.2: Distribution of age categories in Caen



Rib sternal ends

The ribs of only six individuals were adequately preserved to apply this ageing method. The phases of the four males and two females are provided in Table 5.2.

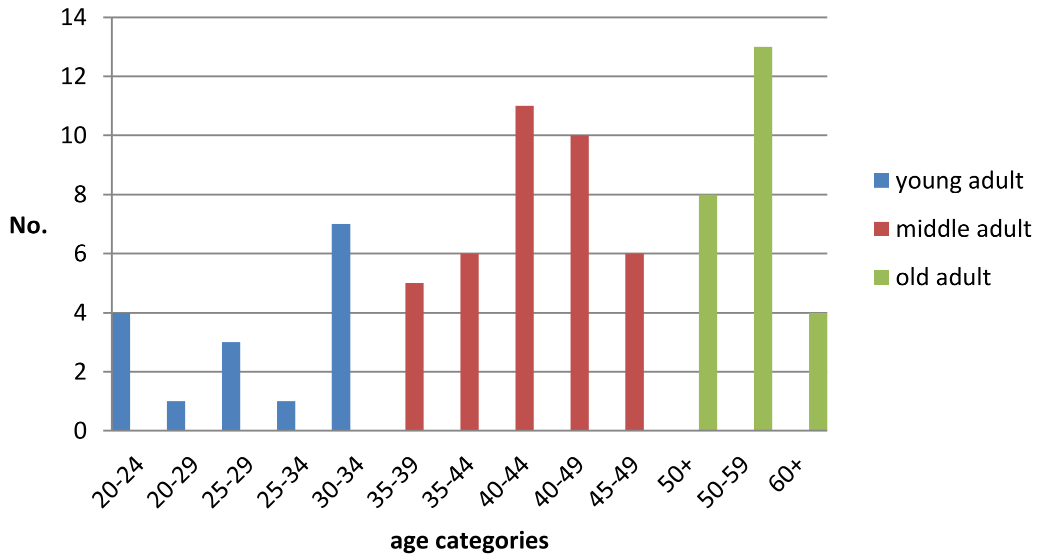
Table 5.2: Age-at-death phases based on sternal rib end ageing in Caen

Male		Female	
Phase	No.	Phase	No.
III (21-46)	0	III (21-53)	1
IV (23-57)	3	IV (26-70)	1
VI (34-86)	1	VI (42-87)	0
Total	**4**	**Total**	**2**

Pelvic auricular surface

The auricular surface ageing method could be applied to 80 skeletons and the results are displayed in Figure 5.3. DAR865 was excluded as the left (25-30) and right (35-44) side provided different results.

Figure 5.3: Distribution of age based on the auricular surface ageing method in Caen



Pubic symphysis

The pubic symphysis could be assessed for 51 individuals (see Table 5.3). This included more males (29) than females (20). The two skeletons which could not reliably be put in the male or female categories were compared to both the male and female casts to attribute an age category. For the males, age categories III, IV and V were best represented as seen in 23/29 (79%) symphyses. The female pubic symphyses were more distributed mainly in the oldest (8/23 - 35%) and youngest (5/23 - 22%) categories.

Table 5.3: Distribution of pubic symphysis stages in Caen

Stage	M	Stage	F	Total
I (15-23)	2	I (15-24)	5	7
II (19-34)	1	II (19-40)	2	4
III (21-46)	5	III (21-53)	2	7
IV (23-57)	11	IV (26-70)	0	11
V (27-66)	7	V (25-83)	3	10
VI (34-86)	3	VI (42-87)	8	12
Total	**29**	**Total**	**20**	**51**

(iii) ***Age and sex distribution***

Table 5.4 combines the sex and age data provided above. It shows that there were a higher proportion of males in the middle adult age category, while the other categories were dominated by females.

Table 5.4: Distribution of age categories according to sex in Caen

	M		**?M**		**?**		**?F**		**F**		**Total**	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Young	2	11	2	11	2	11	5	27	7	38	18	100
Middle	10	27	10	27	1	2	6	16	9	25	36	100
Old	9	36	2	8	1	4	6	24	7	28	25	100
Adult	5	23	2	9	0	0	10	47	4	19	21	100
Total	**26**	**26**	**16**	**16**	**4**	**4**	**27**	**2**	**27**	**27**	**100**	**100**

5.2.2 Dental disease

(i) ***Inventory***

A normal adult dentition contains 32 teeth, and approximately one third of the expected teeth for all individuals studied were present (1046/3200 – 33%) with a further 43 (1.3%) present where only the root remained because of the effect of wear or caries (see Table 5.5). Seven hundred and five teeth (22.0%) were lost ante-mortem.

Table 5.5: Dental inventory in Caen

	No.	%
P	1046	32.7
NP	758	23.7
X	705	22.0
/	648	20.0
R	43	1.3
Total	**3200**	**100**

P: present; NP: not present; X: ante-mortem tooth loss;
/: post-mortem tooth loss; R: only root present.

Looking at individuals rather than the teeth present, 84 individuals had at least one tooth present for observation and 75 had lost teeth ante-mortem. There was no dental information for eight individuals. There were three individuals who had lost all their teeth ante-mortem.

(ii) ***Caries***

The true prevalence rate of caries was low with 156 of 1088 (14%) of teeth affected (156/1088). However, Table 5.8 shows that the majority (70%) of people with teeth present were affected (59/84). There were no significant differences between the sexes (Table 5.6) or age categories (Table 5.7).

Table 5.6: CPR of caries and sex in Caen

	Male		**?**		**Female**		**Total**	
	No.	%	No.	%	No.	%	No.	%
Caries	21	62	2	67	35	74	58	69
No caries	13	38	1	33	12	26	26	31

Table 5.7: CPR of caries and age categories in Caen

	Caries		No caries		Total	
	No.	%	No.	%	No.	%
Adult	14	78	4	22	18	100
MidAdult	18	64	10	36	28	100
OldAdult	11	55	9	45	20	100
YoAdult	15	83	3	17	18	100

Table 5.8: CPR of caries in individuals with teeth from Caen

	No.	%
No caries	25	30
Caries	59	70
Total	**84**	**100**

There was a statistically significant difference in the prevalence of caries between the different types of teeth (χ^2:33.3 p=<0.001, df: 3; V: 0.175). Figure 5.4 shows that over half of the carious teeth were molars. A much larger proportion of the molars present (80/344 - 23%) was affected than the canines (16/191 - 8%) (see Table 5.9).

Figure 5.4: Distribution of caries by tooth category in Caen (I: incisor, C: canine, PM: premolar, M: molar)

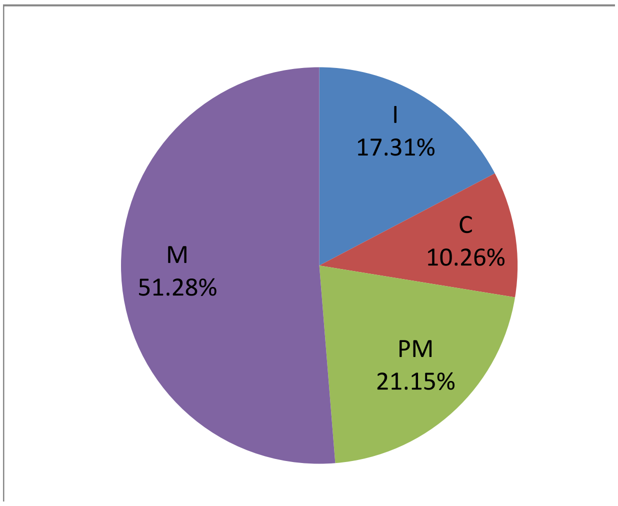
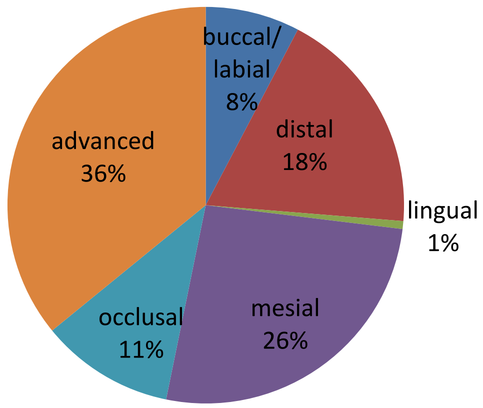


Table 5.9: TPR of caries per tooth category in Caen

	Incisors		**Canines**		**Premolars**		**Molars**		**Total**	
	No.	%	No.	%	No.	%	No.	%	No.	%
Caries	27	11	16	8	33	11	80	23	156	14
No caries	212	89	175	92	281	90	264	77	932	86
Total	**239**		**191**		**314**		**344**		**1088**	

In 36% (56/156) of teeth the caries lesion affected multiple surfaces and was too advanced to determine its source of origin. If only one surface was affected the mesial surface seemed to be affected most and the lingual surface the least (see Figure 5.5).

Figure 5.5: Caries prevalence by tooth surface in Caen



(iii) ***Periapical lesions***

Periapical lesions were not common in this population. Sixty-nine individuals had at least part of the maxilla present for observation and only nine of those showed one or more peri-apical lesions (13%). This is, however, likely to be an underestimate as periapical lesions do not always have a visible aperture and radiography was not available. Looking at the areas involved, there were 17 periapical lesions out of 912 tooth sockets (1.9%). One skeleton had a deformation of the maxilla at the level of the premolars on the right side and was excluded from further analysis.

5.2.3 Indicators of adaptation

(i) ***Dental enamel hypoplasia (DEH)***

Dental enamel hypoplasia was present in 141 teeth (13.0%) with 86 individuals displaying mild and 55 displaying severe DEH. Observation was impossible in 127 teeth due to attrition, caries or calculus. Taking these out of the equation means that 14.7% (141/962) of the recorded teeth displayed DEH. Forty-one of the 84 (49%) individuals with teeth preserved for observation were affected. This is likely to be an underestimate as DEH is more common in the anterior teeth, which are often lost post-mortem. There was no significant difference in the prevalence of DEH in males and females (Table 5.10) or age categories (Table 5.11). Consideration of different tooth categories showed that the incisors, canines and premolars had 10 - 14% prevalence, while DEH was only present in 2% (6/295) of the molars (Figure 5.6 and Table 5.12). The differences in severity between tooth categories in Figure 5.7 and Table 5.13 is statistically significant (χ^2:29.7 p=<0.001, df: 3; V: 0.459).

Table 5.10: CPR of DEH by sex in Caen

	DEH		**No DEH**		**Total**	
Sex	No.	%	No.	%	No.	%
M	20	59	14	41	34	100
F	20	43	26	57	46	100
?	1	25	3	75	4	100

Table 5.11: CPR of DEH and age in Caen

	DEH		**No DEH**		**Total**	
	No.	%	No.	%	No.	%
Adult	6	33	12	67	18	100
MidAdult	16	57	12	43	28	100
OldAdult	8	40	12	60	20	100
YoAdult	11	61	7	39	18	100

Figure 5.6: TPR of DEH by tooth category in Caen (I: incisor, C: canine, PM: premolar, M: molar)

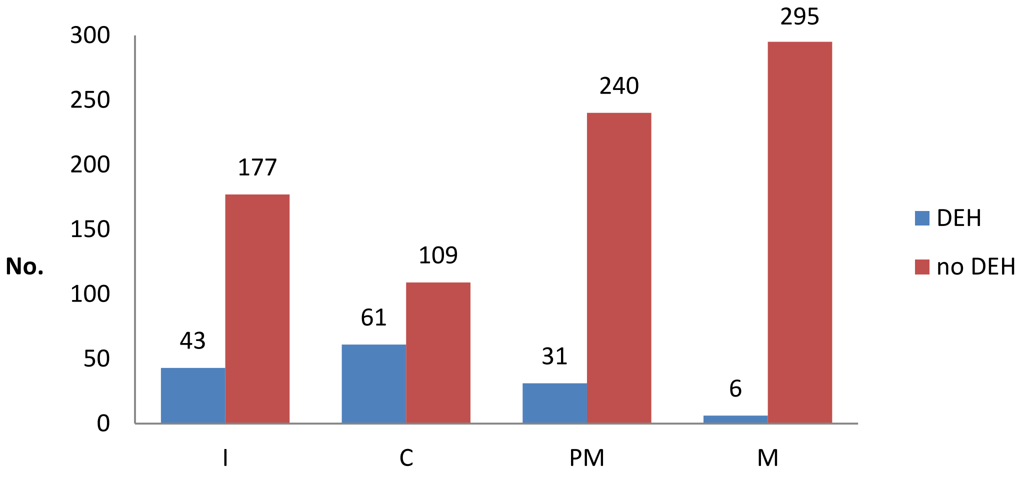


Table 5.12: TPR of DEH by tooth category in Caen

	Incisors		Canines		Premolars		Molars		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
DEH	43	20	61	36	31	11	6	2	141	15
No DEH	177	80	109	64	240	89	295	98	821	85
Total	**220**	**100**	**170**	**100**	**271**	**100**	**301**	**100**	**962**	**100**

Figure 5.7: Mild vs severe dental enamel hypoplasia in tooth categories in Caen (I: incisor, C: canine, PM: premolar, M: molar)

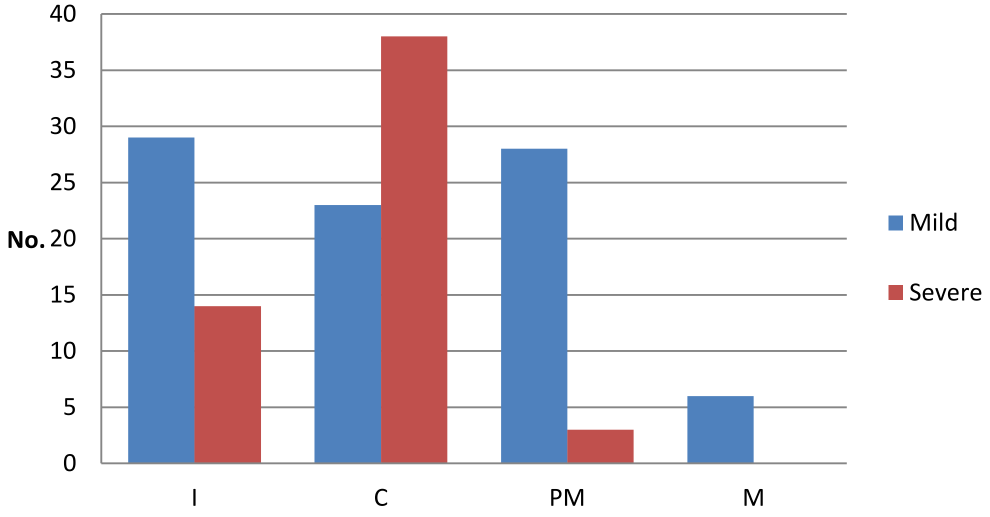


Table 5.13: Severity of DEH per tooth category in Caen

	Incisors		**Canines**		**Premolars**		**Molars**		**Total**	
	No.	%	No.	%	No.	%	No.	%	No.	%
Mild	29	13	23	14	28	10	6	2	86	9
Severe	14	6	38	22	3	1	0	0	55	6
None	177	80	109	64	240	89	295	98	821	85
Total	**220**	**100**	**170**	**100**	**271**	**100**	**301**	**100**	**962**	**100**

(ii) ***Periosteal reaction on the tibiae***

Both tibiae were preserved for observation in 78 individuals. Periosteal reaction was present in 27 (35%). The majority of the periosteal reaction was diffuse (47/59, 76%) and almost 80% was lamellar bone (see Figure 5.8). In addition, the posterior surface was affected significantly less than the medial or lateral surfaces (see Figure 5.9 and Table 5.14). Even though most periosteal reaction was diffuse, only two individuals showed periosteal reaction along the length of the tibiae. There was no significant difference between the proportion of lesions on the left and right sides.

Figure 5.8: Type of bone formation in Caen (TPR)

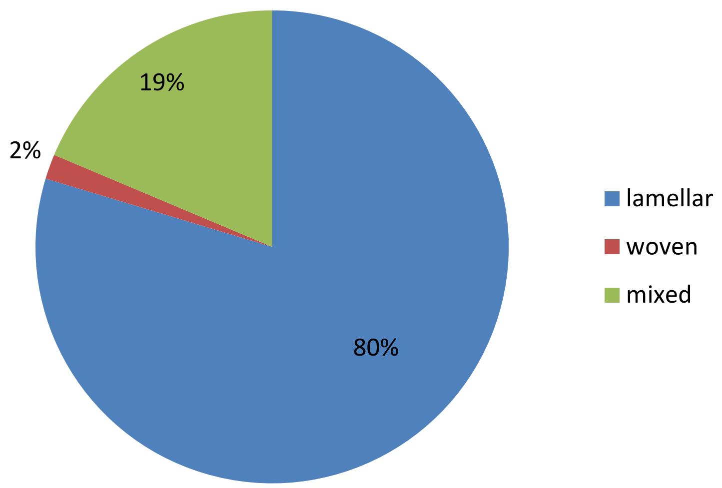


Figure 5.9: Distribution of periosteal reaction on the tibia shaft in Caen

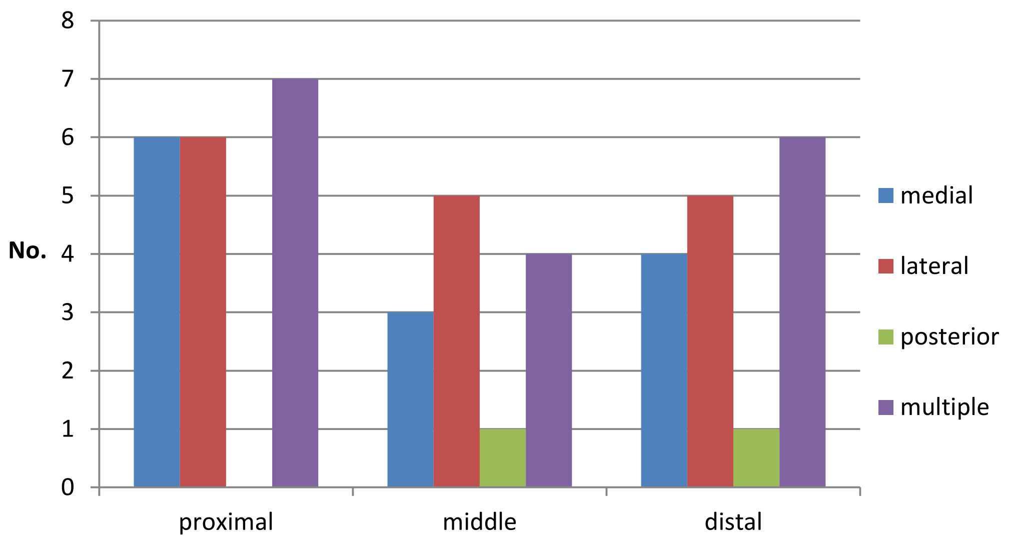


Table 5.14: Distribution of periosteal reaction along the tibiae shaft in Caen

	Proximal		**Middle**		**Distal**		**Total**	
	No.	%	No.	%	No.	%	No.	%
Medial	6	13	3	6	4	8	13	27
Lateral	6	13	5	10	5	10	16	33
Posterior	0	0	1	2	1	2	2	4
Multiple	7	15	4	8	6	13	17	35
total	**19**	**40**	**13**	**27**	**16**	**33**	**48**	**100**

Demography

Fourteen of the individuals were male or probably male, 15 female or probably female, and for one individual sex could not be reliably estimated. The three individuals without periosteal reaction were all in the female categories.

(iii) ***Cribra orbitalia***

At least one orbit was sufficiently preserved for observation in 67 skeletons. Twenty of those (30%) had only one orbit present (eleven left and nine right). Eleven individuals (16%) were affected. There was no difference between the age categories (Table 5.16) or the sexes (Table 5.15).

Table 5.15: CPR of cribra orbitalia by sex in Caen

	No cribra oribitalia	**Cribra oribitalia**	**Total**
M	84	16	**100**
F	82	17	**100**
?	100	0	**100**
Total	**83**	**16**	**100**

Table 5.16: CPR of cribra orbitalia by sex per age category in Caen

	No cribra orbitalia		Cribra orbitalia		Total	
	No.	%	No.	%	No.	%
YoAdult	10	83	2	17	12	100
MidAdult	16	76	5	24	21	100
OldAdult	13	93	1	7	14	100.
Adult	17	85	3	15	20	100
Total	**56**	**84**	**11**	**16**	**67**	**100**

(iv) ***Stature***

Stature could be calculated for 61 individuals. Figure shows the distribution of stature by sex with the error ranges dependent on the long bone used (Table 5.17). The females ranged from 141cm to 176cm with an average of 157cm and standard deviation of 7.7, and the males from 159cm to 177cm with an average of 169cm and standard deviation of 4.6. The stature sex discrimination ratio for this population is 1.08. There does not seem to be an association between age at death and stature (Table 5.18).

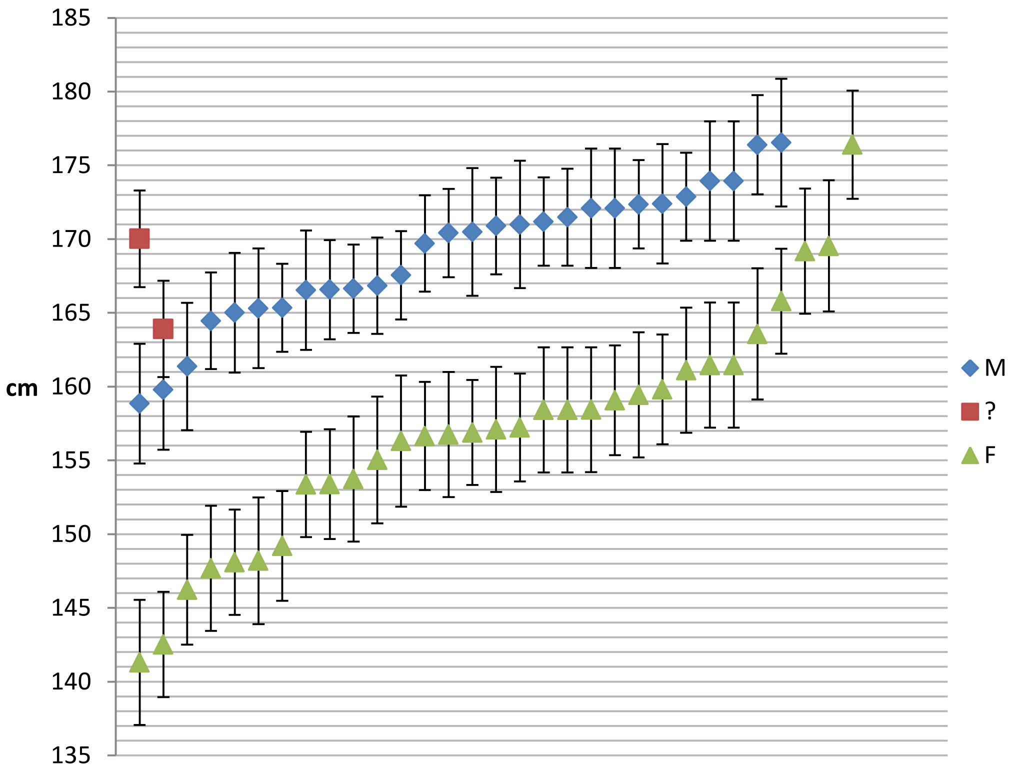
Table 5.17: Long bone and side used for stature in Caen

	Left	Right	Right-left	Total
Femur + tibia	5	5	1	11
Femur	4	5	0	9
Tibia	3	2	0	5
Fibula	3	1	0	4
Humerus	14	9	0	23
Radius	1	2	0	3
Ulna	4	2	0	6
Total	**34**	**26**	**1**	**61**

Table 5.18: Average stature per age category in Caen

	Male		Female		Total	
	No.	Average stat. (cm)	No.	Average stat. (cm)	No.	Average stat. (cm)
Young	3	169	11	157	14	159
Middle	14	168	10	156	24	163
Old	6	171	3	153	9	165
Adult	5	168	7	159	12	163
Total	**28**	**169**	**31**	**157**	**59**	**163**

Figure 5.10: Stature calculations with error ranges in Caen



(v) ***Multiple indicators***

Comparing the presence of the different indicators in the same skeleton shows that cribra orbitalia, dental enamel hypoplasia and periosteal reaction on the tibiae were all present in only one skeleton (see Table 5.19). When only one indicator was recorded this was dental enamel hypoplasia in 11 instances, cribra orbitalia in six and periosteal reaction on the tibiae in eight skeletons. There is a difference in the stature sex discrimination ratio between those with DEH (1.08) and without DEH (1.06) (see Table 5.20).

Table 5.19: Co-ocuurance of multiple indicators within one skeleton in Caen (cribra orbitalia, dental enamel hypoplasia, periosteal reaction on the tibiae)

Number of indicators present	No.
3 indicators	1
2 indicators	5
1 indicator	25
No indicators	10
Total	**41**

Table 5.20: DEH and stature in Caen

	DEH		NO DEH	
	M	**F**	**M**	**F**
Average (cm)	170	157	168	158
SD	4.5	7.0	3.3	7.2
SSD ratio	1.08		1.06	

5.2.4 Respiratory disease

(i) ***Maxillary sinusitis***

Ninety maxillary sinuses were recorded from 55 individuals. Eleven individuals had only one sinus present and those were equally divided between the left (six) and right (five) sides. Maxillary sinusitis was present in 62 of the 90 sinuses (69%) (See Table 5.21).

Table 5.21: TPR of maxillary sinusitis in Caen

	No sinusitis	Sinusitis	Total
Left	12	33	45
Right	16	29	45
Total	**28**	**62**	**90**

Maxillary sinusitis was present in 71% (39/55) of individuals with at least one sinus present for observation. This rose to 80% (28/35) if only the skeletons with both sinuses present are included and reduced to 55% (11/20) when only one sinus was present for observation. Nevertheless, asymmetrical involvement was uncommon, and of the 35 with both sinuses present, only five (14%) displayed bone changes in only one sinus.

The endoscope was successfully used for three of the completely preserved and intact sinuses, all of which showed maxillary sinusitis.

Demography

Maxillary sinusitis was quite common in all the age categories and they appear to have been similarly affected (see Table 5.22). Young and mid-adults appeared to be affected similarly (75% vs 78%), but there was a slight decline in the oldest age category (67%). The difference could be due to the small sample size. A Fisher's exact test showed that this was not statistically significant (χ^2: 1.217 p=0.749, df: 3; Fisher's exact: p=0.777).

Table 5.22: Age distribution of individuals with maxillary sinusitis in Caen

	No sinusitis		Sinusitis		Total	
	No.	%	No.	%	No.	%
Young adult	3	25	9	75	12	100
Middle adult	4	22	14	78	18	100
Old adult	5	33	10	67	15	100
Adult	4	40	6	60	10	100
Total	**16**	**29**	**39**	**71**	**55**	**100**

There was also no significant difference between males and females (see Figure 5.11 and Table 5.23). This was also supported by a chi-squared test (χ^2:0.001, p=0.999, df: 2) in maxillary sinusitis prevalence between males (72% - 16/21) and females (71% - 23/31). The two individuals for whom sex could not be estimated were equally divided.

Figure 5.11: Sex distribution of maxillary sinusitis in Caen

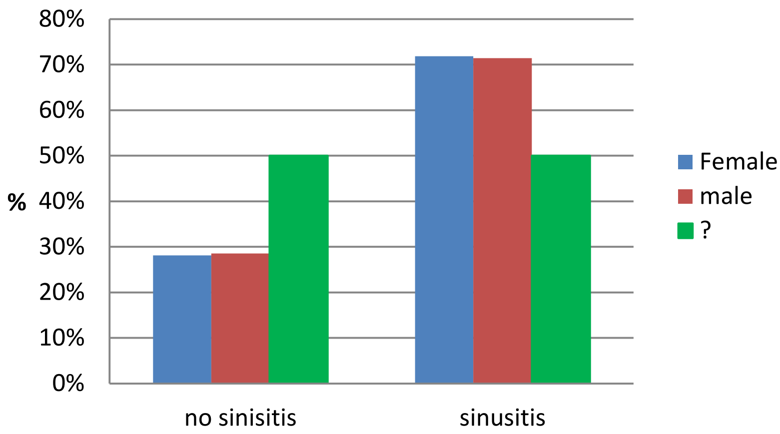


Table 5.23: CPR of maxillary sinusitis and sex in Caen

	Female		Male		?		Total	
	No.	%	No.	%	No.	%	No.	%
No sinusitis	9	28	6	29	1	50	16	29
Sinusitis	23	72	15	71	1	50	39	71
Total	**32**	**100**	**21**	**100**	**2**	**100**	**55**	**100**

Dental disease and sinusitis

The distribution of dental caries and sinusitis was not correlated (χ^2:1.98, p=0.159, df: 1). Table 5.24 shows that the 11 individuals that did not have evidence for caries, 10 showed sinusitis. On the other hand, of the 33 that had caries lesions recorded, about two thirds (23/33) also had maxillary sinusitis.

None of the abscesses drained into the sinus and therefore cannot be proven to be directly linked to sinusitis. However, five of the seven individuals with peri-apical lesion also had sinusitis (71 %).

Table 5.24: Co-occurrence of caries and maxillary sinusitis in Caen

	No sinusitis		Sinusitis		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**
No caries	1	2	10	23	11	25
Caries	10	23	23	52	33	75
Total	**11**	**25**	**33**	**75**	**44**	**100**

(ii) ***Periosteal rib lesions***

Three of the hundred individuals recorded had no ribs preserved for observation. Five were excluded as there was also evidence of trauma on the ribs. A further six had to be excluded because the rib surfaces were damaged post-mortem and could not be recorded. In the remaining 91 individuals, 58 showed rib lesions (64%) (see Figure 5.25), and of those affected, the ribs of the majority were bilaterally involved (45/58 or 79%). However, for three skeletons the asymmetry may be due to the small number of ribs preserved from one side of the rib cage. Looking at the number of ribs present, 401 of the 1809 ribs present were affected (22%).

Table 5.25: CPR of periosteal rib lesions in Caen

	No.	%
Absent	32	37
Present	54	63
Total	**86**	**100**

Demography

Figure 5.12 shows the similar distribution of rib lesions in males and females. There was no statistically significant difference between the sexes (χ^2:1.19, p=0.276, df: 1). There was, however, a significant difference between the age categories (χ^2: 9.70, p=0.021, df: 3) (see Figure 5.13 and Table 5.26).

Figure 5.12: CPR of periosteal rib lesions by sex in Caen

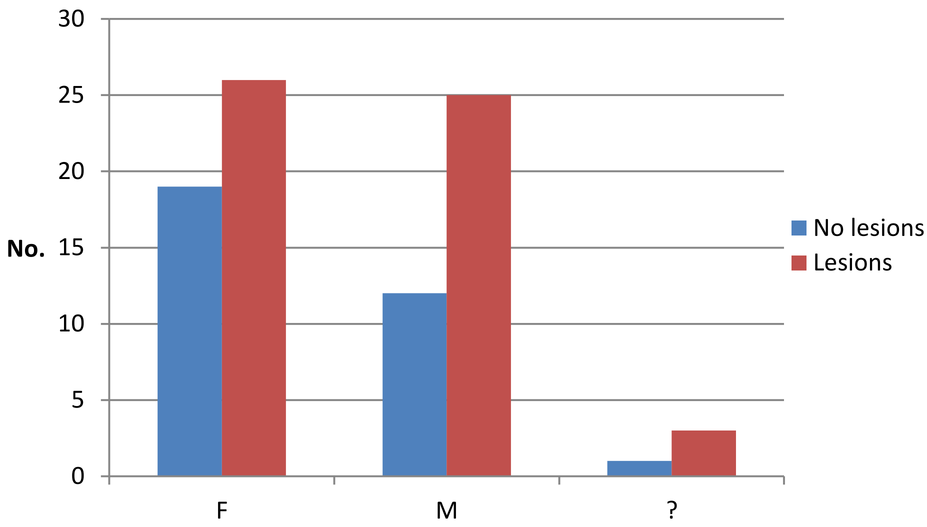


Figure 5.13: CPR of periosteal rib lesions and age category in Caen

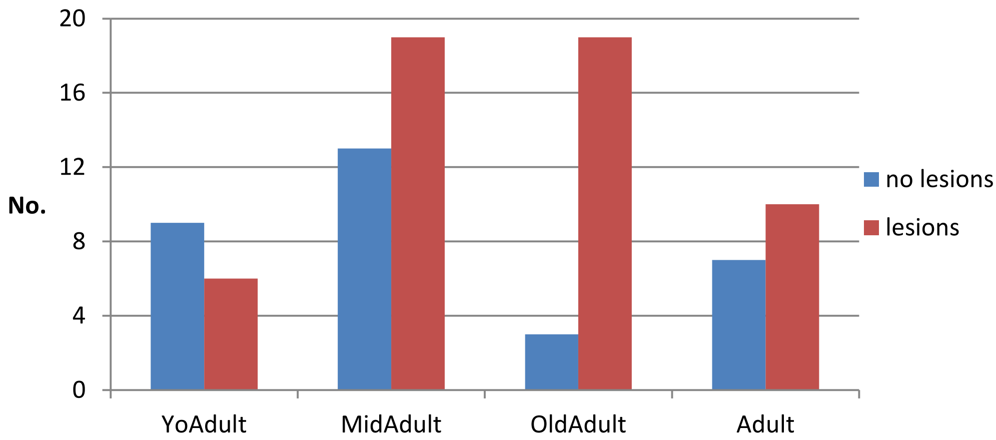


Table 5.26: CPR of periosteal rib lesions and age category in Caen

	No lesions		lesions		Total	
	No.	%	No.	%	No.	%
YoAdult	10	11	6	7	16	18
MidAdult	13	14	22	24	35	38
OldAdult	3	3	19	21	22	24
Adult	7	8	11	12	18	20
Total	33	36	58	64	91	100

(iii) ***Ribs lesions and maxillary sinusitis***

There does not appear to be an association between the presence of rib lesions and the presence of maxillary sinusitis (see Table 5.27), as seen in a chi-squared test (χ^2: 1.5432, p=0.21414, df: 1).

Table 5.27: Co-occurance of periotseal rib lesions and maxillary sinusitis in individuals from Caen

	No sinusitis		Sinusitis		Total	
	No.	%	No.	%	No.	%
No rib lesion	8	15	14	27	22	43
Rib lesion	6	11	23	45	29	56
Total	**14**	**27**	**37**	**72**	**51**	**100**

5.3 Canterbury

5.3.1 Demography

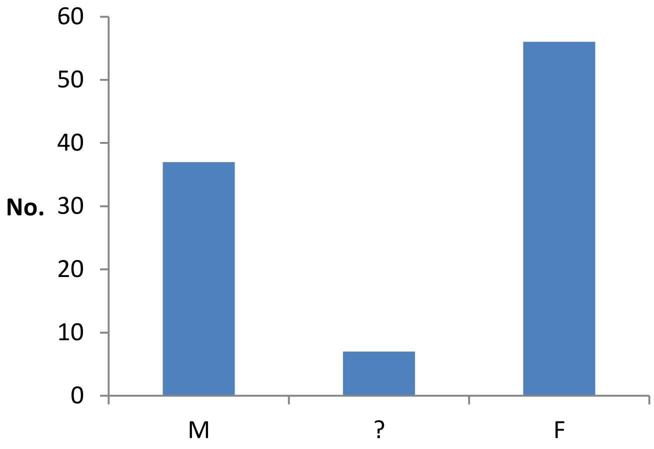
(i) ***Sex estimation***

From the 100 skeletons analysed 93 could be categorised in the male or female ranges (see Table 5.28 and Figure 5.14). This was divided into 37 (40%) in the male categories and 56 (60%) in the female categories.

Table 5.28: Sex distribution in Canterbury

Sex	No.
M	21
?M	16
?	7
?F	31
F	25
Total	**100**

Figure 5.14: "Simplified" sex distribution in Canterbury

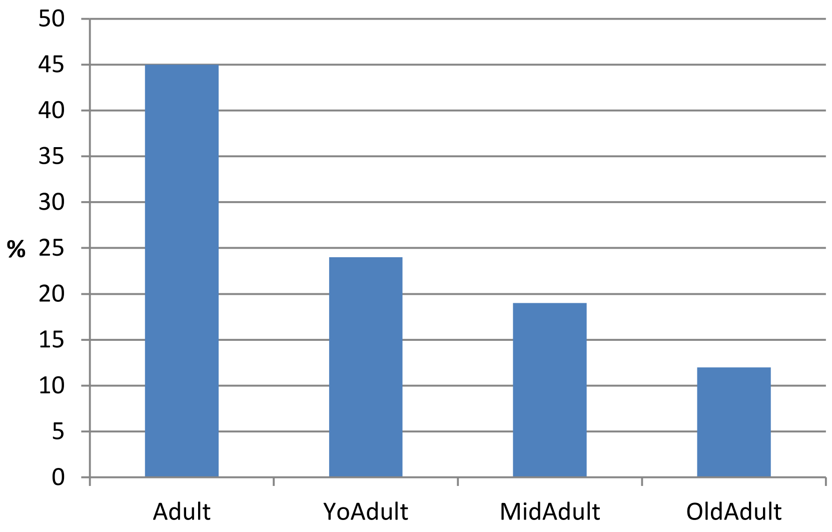


(ii) ***Age estimation***

Age categories

Almost half (45) of the skeletons in Canterbury could not be assigned an age category (see Figure 5.15). Of the 55 that could be aged, 24 (43%) were categorised as young adult. Only 12 (22%) were assigned the oldest age category.

Figure 5.15: Distribution of age categories in Canterbury



Sternal rib ends

The sternal rib ends of 10 skeletons could be analysed (see Table 5.29): three were male, and seven female. Apart from one male, they all fall within the phases II to IV.

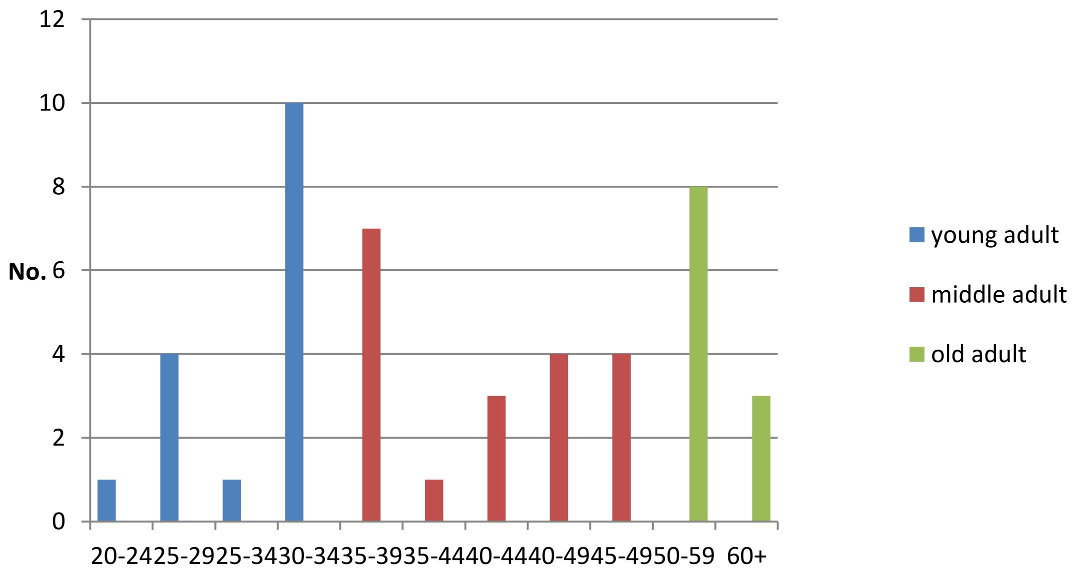
Table 5.29: Age-at-death phases based on sternal rib end ageing in Canterbury

M		F	
II (18-25)	0	II (16-20)	2
III (19-33)	2	III (20-24)	3
IV (22-35)	0	IV (24-40)	2
VIII (44-85)	1		
Total	**3**		**7**

Pelvic Auricular surface

The auricular surface could be assessed for 46 skeletons. Sixteen of those (35%) fell in the young adult ranges, 19 (41%) in the middle adult and 11 (24%) in the old age category se Figure 5.16).

Figure 5.16: Distribution of age based on the auricular surface ageing method in Canterbury



Pubic symphysis

The pubic symphysis was preserved in 19 skeletons: seven male and twelve female. Figure 5.30 shows that the males and females were distributed across the phases.

Table 5.30: Distribution of pubic symphysis stages in Canterbury

Male		Female	
phase	No.	phase	No.
I (15-23)	0	I (15-24)	1
II (19-34)	1	II (19-40)	4
III (21-46)	3	III (21-53)	2
IV (23-57)	2	IV (26-70)	1
V (27-66)	1	V (25-83)	2
VI (34-86)	0	VI (42-87)	2
Total	**7**		**12**

(iii) ***Age and sex distribution***

The data on sex and age described above are combined in Figure 5.31. It shows that 59% of old adults was male (7/12), but females dominated the young and middle age categories.

Table 5.31: Distribution of age categories according to sex in Canterbury

	M		**?M**		**?**		**?F**		**F**		**Total**	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Young	4	17	4	17	0	0	6	25	10	42	24	100
Middle	4	21	1	5	0	0	6	32	8	42	19	100
Old	5	42	2	17	1	8	3	25	1	8	12	100
Adult	8	18	9	20	6	13	16	36	6	13	45	100
Total	**21**	**21**	**16**	**16**	**7**	**7**	**31**	**31**	**25**	**25**	**100**	**100**

5.3.2 Dental disease

(i) ***Dental inventory***

From the 100 skeletons, dentition was at least partially present for 87 individuals. A total of 1347 teeth were preserved (42 % of the expected teeth). Almost 20% of teeth were lost ante-mortem (see Table 5.32).

Table 5.32: Dental inventory Canterbury

	No.	%
P	1253	39.1
R	96	3.00
/	497	15.5
X	623	19.5
NP	731	22.8
Total	**3200**	**100**

(ii) ***Caries***

Dental caries affected 44 individuals from the 87 with the dentition preserved (54%) as shown in Table 5.33.. There was no significant difference between males and females (Table 5.34) or between the age categories (Table 5.35).

Table 5.33: CPR of dental caries in Canterbury

	No.	%
Without caries	40	46%
With caries	47	54%
Total	**87**	

Table 5.34: CPR of caries and sex in Canterbury

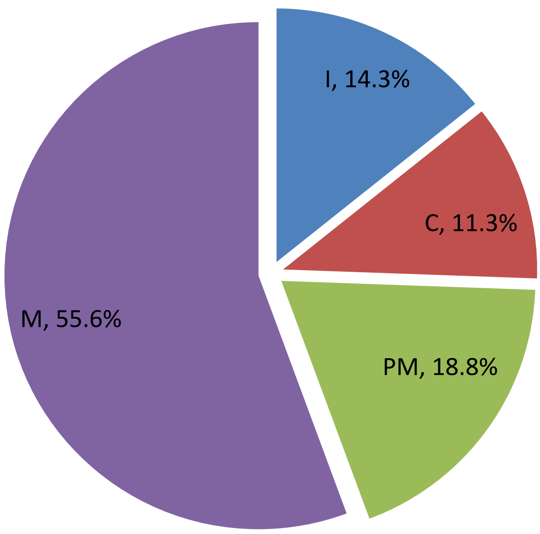
	M		F		?		Total	
	No.	%	No.	%	No.	%	No.	%
No caries	14	45	25	49	1	20	40	46
Caries	17	55	26	51	4	80	47	54
Total	**31**	**100**	**51**	**100**	**5**	**100**	**87**	**100**

Table 5.35: CPR of caries and age categories in Canterbury

	No caries		Caries		Total	
	No.	%	No.	%	No.	%
YoAdult	9	38	15	63	24	100
MidAdult	10	59	7	41	17	100
OldAdult	5	56	4	44	9	100
Adult	16	43	21	57	37	100
Total	**40**	**46**	**47**	**54**	**87**	**100**

Caries was recorded in 133 of the 1347 teeth present (9.9%). Figure 5.17 shows that more than half of the carious lesions were recorded in the molar teeth (74/133 – 55.6%).

Figure 5.17: Caries in the different tooth categories in Canterbury (I: incisor, C: canine, PM: premolar, M: molar)



(iii) ***Peri-apical lesions***

Peri-apical lesions were present in only 16% (13/81) of the individuals with maxilla preserved (see Table 5.36).

Only 2% (26/1057) of maxillae were affected. Apart from one individual with seven peri-apical lesions (NGA88_0563), most individuals had only one to three lesions.

Table 5.36: CPR of peri-apical lesions in Canterbury

	No.	%
No lesion	68	84
Lesion	13	16
Total	**81**	**100**

5.3.3 Indicators of adaptation

(i) ***Dental enamel hypoplasia***

Dental enamel hypoplasia was present in 53 individuals (61%) and affected 21.4% (208/974) of the teeth. However, Figure 5.18 shows that frequency varied widely between the tooth categories, with about half of the canines affected (84/165 - 50.9%) and only 1.3% (4/318) of the molars.

Figure 5.18: TPR (presence/absence) of DEH by tooth category in Canterbury (I: incisor, C: canine, PM: premolar, M: molar)

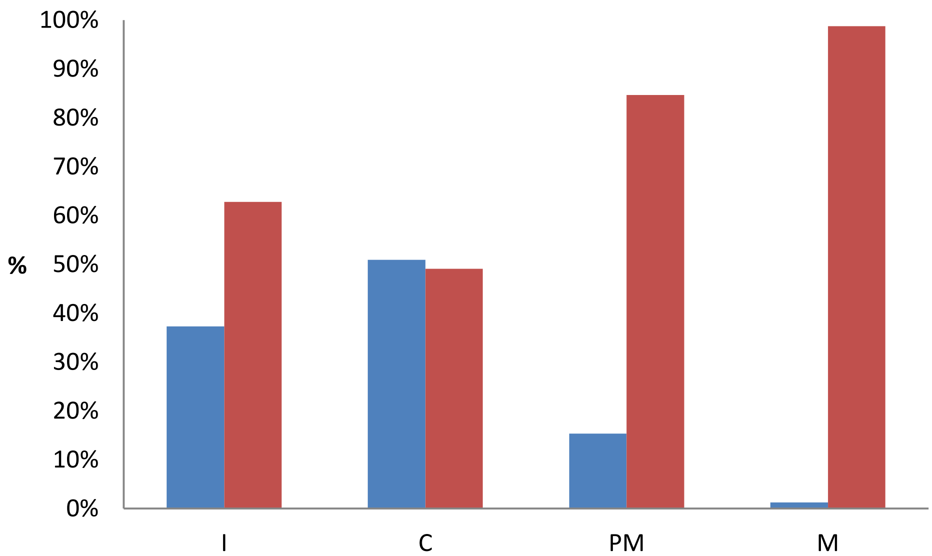


Figure 5.19 indicates that mild and severe DEH are present equally in the incisors, and that the DEH in premolars is predominantly mild. Only two molars display DEH – one of which is mild and the other one severe. There was no significant difference between males and females (Table 5.37) or between age categories (Table 5.38).

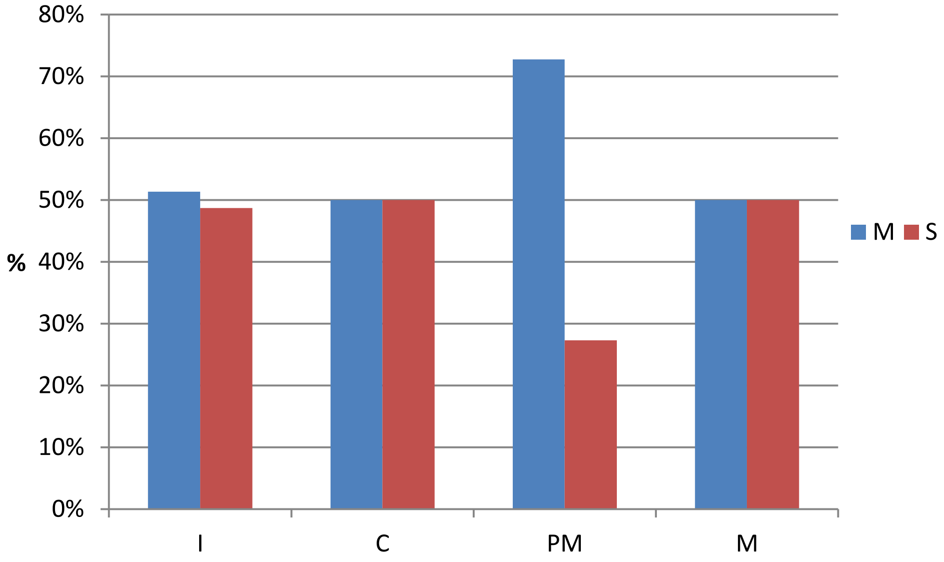
Table 5.37: CPR of DEH by sex in Canterbury

	M		**F**		**?**		**Total**	
	No.	%	No.	%	No.	%	No.	%
No DEH	14	45	18	35	2	40	34	39
DEH	17	55	33	65	3	60	53	61
Total	**31**	**100**	**51**	**100**	**5**	**100**	**87**	**100**

Table 5.38: CPR of DEH by age categories in Canterbury

	No DEH		**DEH**		Total	
	No.	%	No.	%	No.	%
YoAdult	5	21	19	79	24	100
MidAdult	8	47	9	53	17	100
OldAdult	3	33	6	67	9	100
Adult	18	49	19	51	37	100
Total	**34**	**39**	**53**	**61**	**87**	**100**

Figure 5.19: Mild vs severe DEH by tooth category in Canterbury (I: incisor, C: canine, PM: premolar, M: molar)



(ii) ***Periosteal reaction on the tibiae***

Table 5.39 shows that periosteal reaction was present on the tibiae in eleven (19%) of the 62 skeletons analysed, five of these eleven had a bilateral diffuse distribution (45%). From the 25 bone sections which had periosteal reaction recorded, 16 (64%) had a diffuse distribution. Figure 5.20 shows the distribution of periosteal bone formation across the tibia. All the bone formation was lamellar in nature. Forty-five percent (five individuals) of the periosteal reaction was bilateral. As would be expected with these small numbers, there is no difference between the sexes (Table 5.40) or age categories (Table 5.41).

Table 5.39: CPR of periosteal reaction on the tibiae in Canterbury

	No.	%
No periosteal reaction	50	82%
Periosteal reaction	11	18%
Total	**61**	

Figure 5.20: Distribution of periosteal reaction along the tibiae in Canterbury

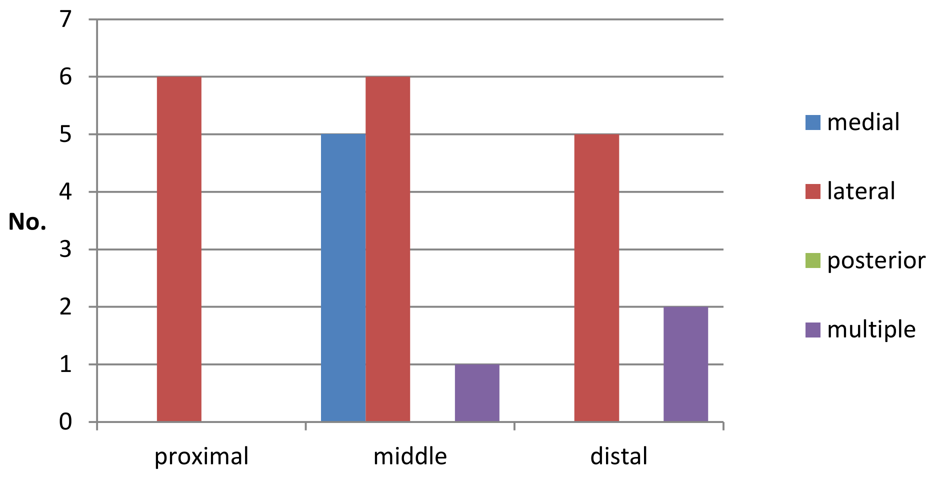


Table 5.40: CPR of periosteal reaction on the tibiae in Canterbury

	M		**F**		**?**		Total	
	No.	%	No.	%	No.	%	No.	%
Periosteal reaction	3	14	7	20	1	20	12	19
No reaction	18	86	28	80	4	80	50	81
Total	21	100	36	100	5	100	62	100

Table 5.41: CPR of periosteal reaction on the tibiae per age category in Canterbury

	Periosteal reaction		**No reaction**		**Total**
	No.	**%**	**No.**	**%**	
YoAdult	3	23	10	77	13
MidAdult	2	15	11	85	13
OldAdult	2	22	7	78	9
Adult	4	15	22	85	26
Total	**11**	**18**	**50**	**82**	**61**

(iii) ***Cribra orbitalia***

Cribra orbitalia was not common in Canterbury (Table 5.42). In the 81 skeletons with at least one orbit preserved, only 6 (7%) displayed cribra orbitalia. This was equally split between males and females (Table 5.43) and age categories (Table 5.44).

Table 5.42: CPR of cribra orbitalia in Canterbury

	No.	%
Cribra	6	7
No cribra	75	93
Total	**81**	

Table 5.43: CPR of cribra orbitalia by sex in Canterbury

	M		F		?		Total	
	No.	%	No.	%	No.	%	No.	%
No cribra orbitalia	27	90	43	93	5	100	75	93
Cribra orbitalia	3	10	3	7		0	6	7
Total	30	100	46	100	5	100	81	100

Table 5.44: CPR of cribra orbitalia by age category in Canterbury

	YoAdult		MidAdult		OldAdult		Adult		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
No cribra orbitalia	19	95	12	92	10	83	34	94	75	93
Cribra orbitalia	1	5	1	8	2	17	2	6	6	7
Total	20	100	13	100	12	100	36	100	81	100

(iv) ***Stature***

Stature could be calculated for 59 skeletons, 23 males (39%), 33 females (56%) and 3 (1%) of the unknown sex group (see Table 5.46 and Figure 5.21). The mean calculated stature was 170cm for males (standard deviation: 6.6) and 160 cm for females (SD: 6.8) with a stature sex discrimination ratio of 1.06. Table 5.45 shows the long bone and side used.The sample sizes in each age category are too small to make meaningful inferences about the differences between them (Table 5.46).

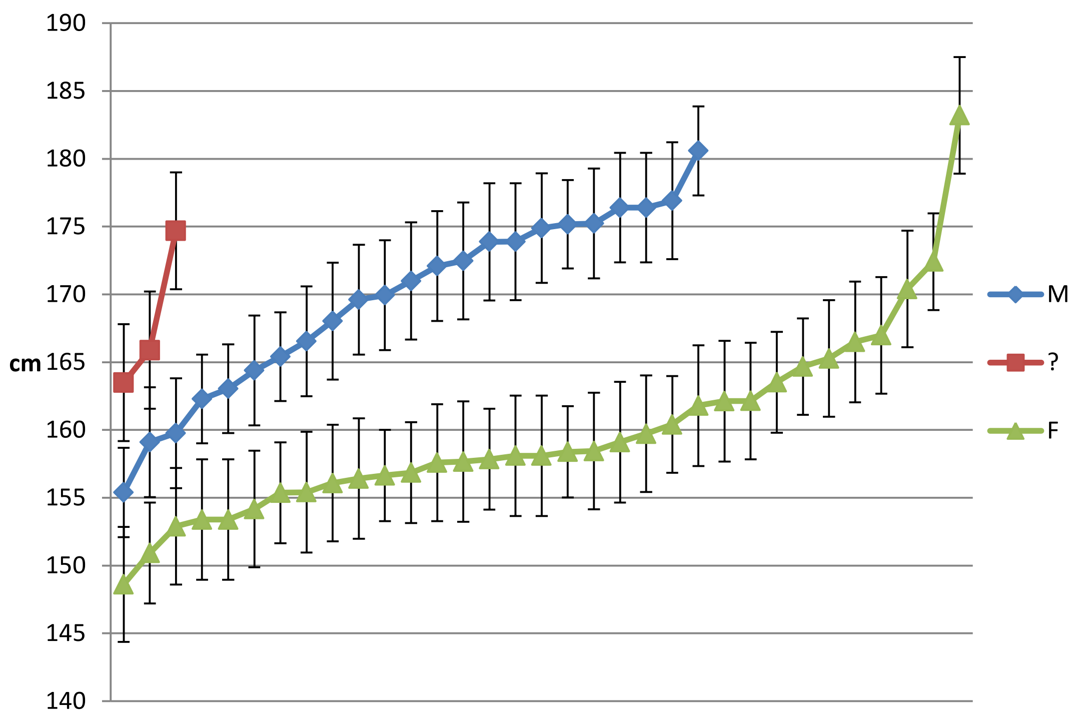
Table 5.45: Long bone and side used for stature at Canterbury

Bone	left	right	Total
Femur	6	3	9
Femur + tibia	1		1
Fibula	3	1	4
Humerus	13	9	22
Radius	2	2	4
Tibia	1	1	2
Ulna	11	6	17
Total	37	22	59

Table 5.46: Stature estimates by age category in Canterbury

	M		?		F		Total No.
	No.	Average stature (cm)	No.	Average stature (cm)	No.	Average stature (cm)	
YoAdult	7	171			8	157	15
MidAdult	3	173			9	160	12
OldAdult	5	169			2	155	7

Figure 5.21: Stature calculation with error ranges in Canterbury



(v) ***Multiple indicators***

Table 5.47 shows that when multiple lesions can be recorded the majority of skeletons only display one lesion (27/43). The majority of these lesions are dental enamel hypoplasia (23/27). **Error! Reference source not found.** shows a difference in stature calculations for males and females with dental enamel hypoplasia. This difference is statistically significant for females (t: -4.015, p= <0.01), but not for males (t: -1.4082, p=0.18). The stature sex discrimination ratio is 1.06 for people with and without dental enamel hypoplasia (see Table 5.48).

Table 5.47: Co-occurance of multiple indicators within one skeleton (cribra orbitalia, DEH, perioseasteal reaction on the tibiae)

Number of indicators	No.
3 indicators	1
2 indicators	6
1 indicator	27
No indicators	6
Total	**43**

Table 5.48: Dental enamel hypoplasia and stature calculation in Canterbury

	DEH		NO DEH	
	M	**F**	**M**	**F**
Average (cm)	167	157	171	161
SD	6.4	2.7	5.6	4.4
SSD ratio	1.06		1.06	

5.3.4 Respiratory disease

(i) ***Maxillary sinusitis***

Ninety-six sinuses were recorded from 64 skeletons, with 46 from the left and 50 from the right sides. An endoscope was used to record 20 intact sinuses. Maxillary sinusitis was present in 41 of the 64 (64%) skeletons analysed, and was mostly bilateral in occurrence. Both sinuses were present in 35 skeletons and twenty of those (57%) had sinusitis on both sides; only eight individuals had no evidence of sinusitis (23%). The unilateral sinusitis was distributed equally between the left and right sides, with four displaying lesions on the left side only, and three on the right only.

Table 5.49 shows that 69% of females were affected and only 58% of males. This is not statistically significant (χ^2: 0.766, p=0.381, df: 1). There is an increase in the prevalence of maxillary sinusitis with age (Table 5.50) There is no link between dental disease and maxillary sinusitis in Canterbury. People with and without sinusitis display carious lesions similarily (see Table 5.51).

Table 5.49: CPR of maxillary sinusitis by sex in Canterbury

	M		F		?		Total	
	No	%	No	%	No	%	No	%
No sinusitis	11	42	11	31	1	33	23	36
Sinusitis	15	58	24	69	2	67	41	64
Total	26	100	35	100	3	100	64	100

Table 5.50: CPR of maxillary sinusitis by age category in Canterbury

	No sinusitis		Sinusitis		Total	
	No.	%	No.	%	No.	%
YoAdult	5	29	12	71	17	100
MidAdult	5	42	7	58	12	100
OldAdult	3	33	6	67	9	100
Adult	10	38	16	62	26	100
Total	23	36	41	64	64	100

Table 5.51: Co-occurrence of caries and maxillary sinusitis in Canterbury

	No sinusitis		Sinusitis		Total %	
	No.	%	No.	%	No.	%
No caries	8	40	15	38	23	39
Caries	12	60	24	62	36	61
Total	20	100	39	100	59	100

(ii) ***Rib lesions***

From the 100 skeletons analysed, only two had no ribs preserved. However, the ribs of a further seven were poorly preserved and were therefore excluded. Another two excluded as they also showed evidence of trauma to the ribs. The data for the remaining are presented here. From the 89 individuals, rib lesions were present in 57 skeletons (63%). Table 5.52 shows that males and females were similarly affected (60%). The prevalence of rib lesions increases with age (see Table 5.53). There were more young people without lesions (13/23-57%) than with lesions.

Table 5.52: CPR of periosteal rib lesions and sex in Canterbury

	Absent		**Present**		**Total**	
	No.	%	No.	%	No.	%
F	20	40	30	60	50	100
?	0	0	5	100	5	100
M	13	38	21	62	34	100
Total	33	37	57	63	89	100

Table 5.53: CPR of periosteal rib lesions and age in Canterbury

	Absent		**Present**		**Total**	
	No.	%	No.	%	No.	%
YoAdult	13	57	10	43	23	100
MidAdult	6	38	10	63	16	100
OldAdult	1	9	10	91	11	100
Adult	13	33	26	67	39	100
Total	**33**	**37**	**56**	**63**	**89**	**100**

(iii) ***Maxillary sinusitis vs rib lesions***

There is an apparent association of rib lesions with maxillary sinusitis (see Table 5.54). However, this is not statistically significant (χ^2: 1.889, p=0.169, df: 1).

Table 5.54: Co-occurance of periosteal rib lesions and maxillary sinusitis in Canterbury

	No sinusitis		**Sinusitis**		**Total**	
	No.	%	No.	%	No.	%
No rib lesions	10	17	10	17	20	34
Rib lesions	12	21	26	45	38	66
Total	22	38	36	62	58	100

5.4 Ghent

5.4.1 Demography

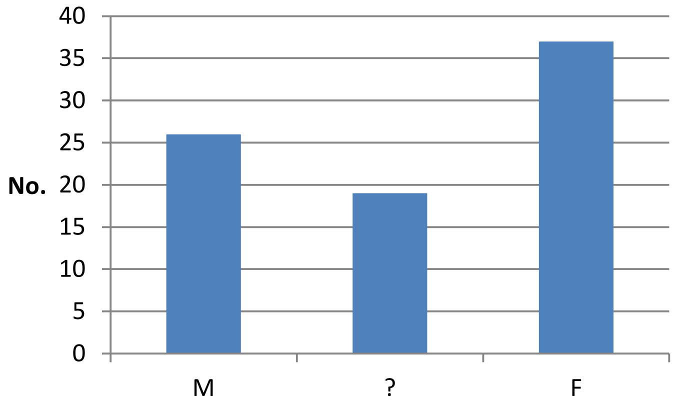
(i) ***Sex estimation***

Eighty-three skeletons were analysed in Ghent. For 19 individuals sex could not be estimated. Of the remaining 64, 27 (42%) were either definitely male or probably male. Thirty-seven (58%) were sexed as definitely female, or probably female (see Table 5.55 and Figure 5.22).

Table 5.55: Sex distribution in Ghent

Sex	No.	%
M	17	20
?M	10	12
?	19	23
?F	16	19
F	21	25
Total	**83**	**100**

Figure 5.22: "Simplified" sex distribution in Ghent

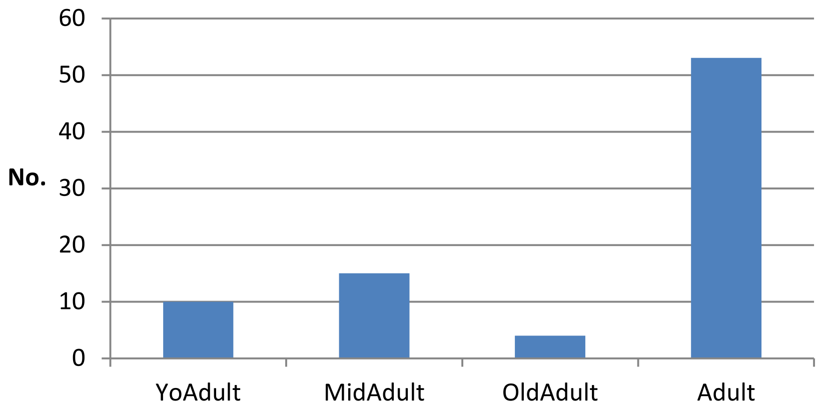


(ii) ***Age estimation***

Age categories

The poor preservation of this population shows in the relatively unsuccessful application of the ageing methods. No age category could be assigned for 64% (53/83) of the skeletons analysed. Over half of those that could be aged were in the middle adult category (17/30 – 57%), and only four (13%) were in the oldest age category (see Figure 5.23).

Figure 5.23: Distribution of age categories in Ghent



Sternal rib ends

The sternal ends of ribs could only be observed in three skeletons, two of which could not be sexed (see Table 5.56). Two of them fell within the range of the young adult age category.

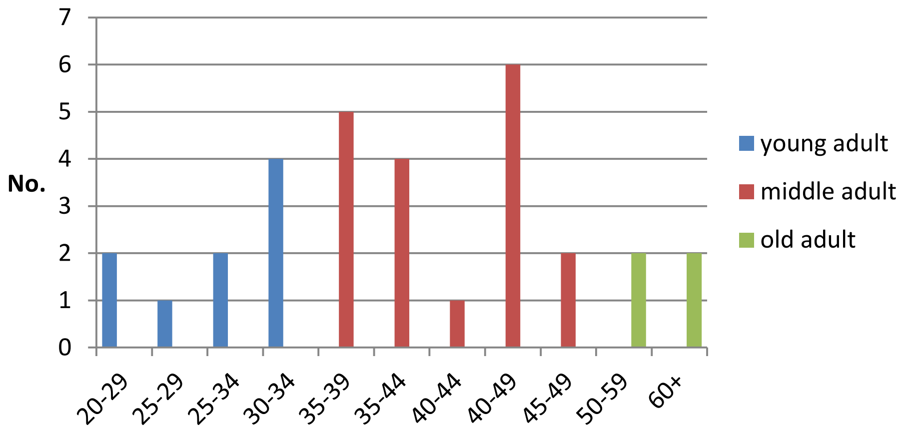
Table 5.56: Age-at-death phases based on sternal rib end ageing in Ghent

SkelID	Sex	RibAgeStage	RibAge
SPP114b	?	IV	26-32
SPP250	M	II	20-23
SPP114c	?	V	33-46

Pelvic Auricular surface

The auricular surface could be observed for 32 skeletons. However, SPP839 had to be excluded as there were different age range estimations for the right (50-60) and left (45-49) auricular surfaces. The middle adult category was most prominently present (18/31 – 58%), followed by the youngest age category (9/31 – 29%). The oldest age category was by far the least represented (4/31 – 13%) (see Figure 5.24).

Figure 5.24: Distribution of age based on the auricular surface ageing method in Ghent



Pubic symphysis

Table 5.57 shows the pubic symphysis age estimates that were recorded for 10 males and six females.

Table 5.57: Distribution of pubic symphysis stages in Ghent

M		F	
I (15-23)	1	I (15-24)	1
II (19-34)	1	II (19-40)	0
III (21-46)	2	III (21-53)	2
IV (23-57)	3	IV (26-70)	3
V (27-66)	3	V (25-83)	0
Total	10		6

(iii) ***Age and sex distribution***

Table 5.58 shows the distribution of age and sex combined. It shows that for 14% of individuals (12/83) neither sex nor age could be estimated. Old adults equally represented across males and females. The differences between males and females were more visible in the younger age categories. The males were equally represented in the young and middle age categories, while the females are barely represented in the youngest age category (2/37 females – 5%).

Table 5.58: Distribution of age categories according to sex in Ghent

	M		**?**		**F**		**Total**	
Age category	No.	%	No.	%	No.	%	No.	%
Adult	17	20	12	14	24	29	53	64
Young adult	4	5	3	4	2	2	9	11
Middle adult	4	5	4	5	9	11	17	20
Old adult	2	2	0	0	2	2	4	5
Total	**27**	**33**	**19**	**23**	**37**	**45**	**83**	**100**

5.4.2 Dental disease

(i) ***Dental inventory***

Forty percent of the expected number of teeth (1058) was preserved for examination. Fifteen of the 82 (18%) skeletons analysed had no teeth present.

Table 5.59 shows that a large proportion of teeth (940, 36.8%) were not present. A further 458 teeth (17.5%) were lost post-mortem, and only 6.4% (168) were lost antemortem.

Table 5.59: Dental inventory in Ghent

	No.	%
P	1021	39
R	37	1
NP	940	36
/	458	17
X	168	6
Total	**2624**	

P: present, R: root only; NP: not present;
/: post-mortem tooth loss; X: ante-mortem tooth loss.

(ii) ***Caries***

Teeth with carious lesions were present in 28 of 69 individuals with teeth preserved (41%). Fifty-eight teeth (5.5%) were affected. Figure 5.25 shows that half of those are molars. There was no difference between males and females (Table 5.60) or the between the age categories (Table 5.61).

Figure 5.25: TPR of caries by tooth category in Ghent
(I: incisor, C: canine, PM: premolar, M: molar)

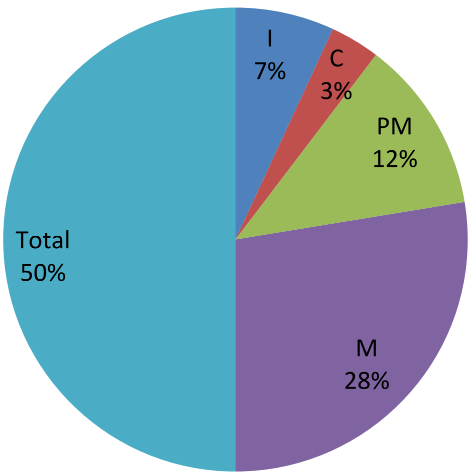


Table 5.60: CPR of caries and sex in Ghent

	M		F		?		Total	
	No.	%	No.	%	No.	%	No.	%
No caries	14	34	16	39	11	27	41	100
Caries	9	32	15	54	4	14	28	100
Total	23	33	31	45	15	22	69	100

Table 5.61: CPR of caries and age categories in Ghent

	No caries		Caries		Total	
	No.	%	No.	%	No.	%
YoAdult	4	50	4	50	8	100
MidAdult	6	46	7	54	13	100
OldAdult	1	33	2	67	3	100
Adult	30	67	15	33	45	100
Total	41	59	28	41	69	100

(iii) ***Peri-apical lesions***

Only three peri-apical lesions were recorded in Ghent in three different individuals. None of the observed lesions connected to the sinus floor.

5.4.3 Indicators of adaptation

(i) ***Dental enamel hypoplasia***

DEH is present in 52% of the dentitions analysed (34/65). Canine teeth are the most often affected (64 of 173, 37% - see Figure 5.26 and Table 5.64). Only 24.3% (31/13) of teeth with have severe DEH (Figure 5.27 and Table 5.65). There is no significant difference between the age categories (Table 5.62) or sexes (Table 5.63).

Figure 5.26: TPR of DEH by tooth category in Ghent (I: incisor, C: canine, PM: premolar, M: molar)

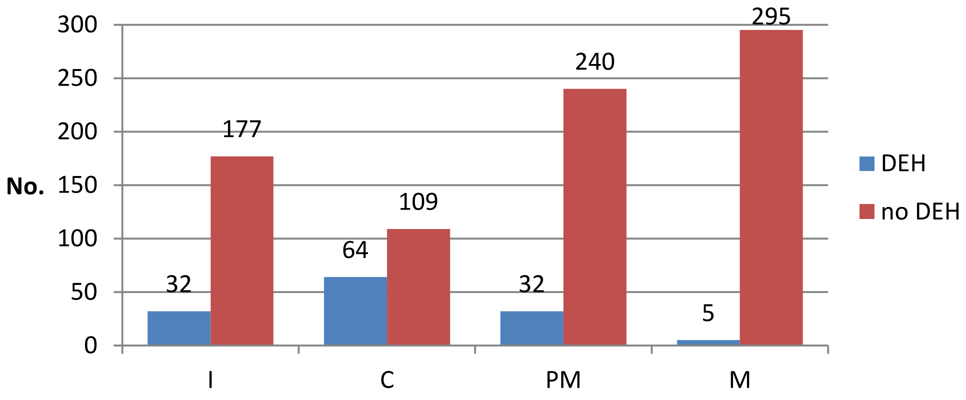


Table 5.62: CPR of DEH by age category in Ghent

	No DEH		DEH		Total	
	No.	%	No.	%	No.	%
YoAdult	4	50	4	50	8	100
MidAdult	5	42	7	58	12	100
OldAdult	3	100	0	0	3	100
Adult	19	41	27	59	46	100
Total	**31**	**45**	**38**	**55**	**69**	**100**

Table 5.63: CPR of DEH by sex in Ghent

	M		F		?		Total	
	No.	%	No.	%	No.	%	No.	%
No DEH	11	48	13	42	7	47	31	45
DEH	12	52	18	58	8	53	38	55

Table 5.64: TPR of DEH by tooth category in Ghent (I: incisor, C: canine, PM: premolar, M: molar)

	I		C		PM		M		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
DEH	32	15	64	37	32	12	5	2	133	14
no DEH	177	85	109	63	240	88	295	98	821	86
total	**209**		**173**		**272**		**300**		**954**	

Figure 5.27: Mild and severe DEH by tooth category in Ghent (I: incisor, C: canine, PM: premolar, M: molar)

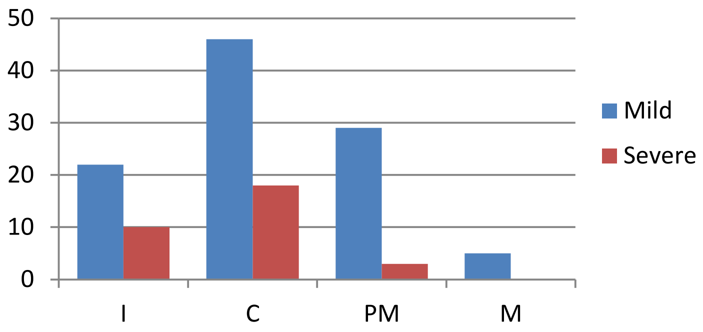


Table 5.65: Mild and severe DEH by tooth category in Ghent (I: incisor, C: canine, PM: premolar, M: molar)

	I		C		PM		M		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Mild	22	69	46	72	29	91	5	100	102	77
Severe	10	31	18	28	3	9	0	0	31	23
Total	32	100	64	100	32	100	5	100	133	100

(ii) ***Periosteal reaction on the tibiae***

Tibiae were completely preserved for 29 skeletons. However, three had to be excluded as their surfaces were eroded and could therefore not be observed accurately. In the remaining 26 skeletons periosteal reaction was present on at least one side of the shaft for 17 (65%) (see Table 5.66). Twelve skeletons (71%) had a bilateral distribution. There was no significant difference between male and female frequencies ($\chi2$: 0.362, Fisher's exact p=0.674, df: 2) as shown in Table 5.67 or age categories (see Table 5.68). Figure 5.28 shows the distribution of the periosteal reaction along the tibiae. All periosteal reaction was recorded as lamellar bone.

Table 5.66: CPR of periosteal reaction on the tibiae from Ghent

	No.	%
No reaction	9	35
Periosteal reaction	17	65
Total	**26**	**100**

Figure 5.28: Distribution of periosteal reaction along the shaft of the tibiae in Ghent

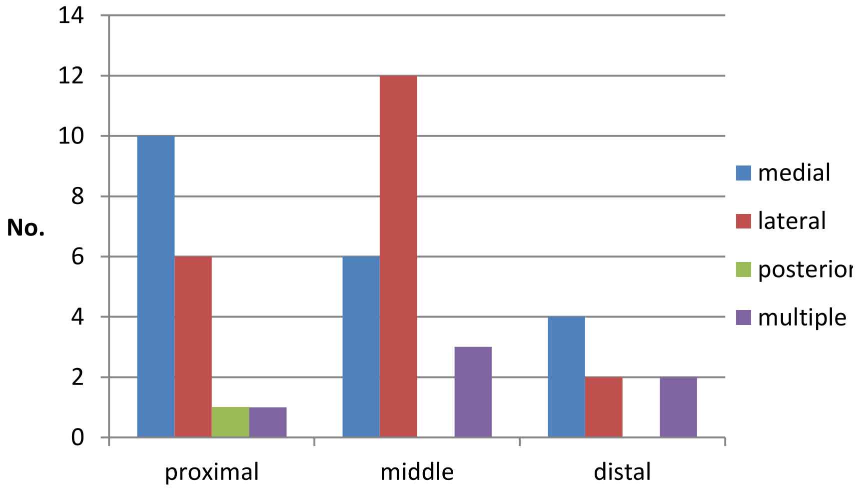


Table 5.67: Distribution of periosteal reaction on the tibiae by sex in Ghent

	M		**F**		**?**		**Total**	
	No.	%	No.	%	No.	%	No.	%
Periosteal reaction	6	67	7	54	4	100	17	65
No periosteal reaction	3	33	6	46	0	0	9	35
Total	**9**	**100**	**13**	**100**	**4**	**100**	**26**	**100**

Table 5.68: Periosteal reaction on the tibiae by age category in Ghent

	Periosteal reaction		**No periosteal reaction**		**Total**	
	No.	%	No.	%	No.	%
YoAdult	3	75	1	25	4	100
MidAdult	3	60	2	40	5	100
OldAdult	2	67	1	33	3	100
Adult	9	64	5	36	14	100
Total	**17**	**65**	**9**	**35**	**26**	**100**

(iii) ***Cribra Orbitalia***

Cribra orbitalia was only present in five individuals (16%) from the 32 that had at least one orbit present (see Table 5.69). Four of those were female, the last one was male. Table 5.70 shows the age distribution of the lesions.

Table 5.69: CPR of cribra orbitalia in Ghent

	No.	**%**
Cribra	5	16
No cribra	27	84
Total	**32**	**100**

Table 5.70: CPR of cribra orbitalia by age category in Ghent

	No cribra orbitalia		Cribra orbitalia		Total	
	No.	%	No.	%	No.	%
Adult	21	95	1	5	22	100
YoAdult	2	50	2	50	4	100
MidAdult	3	60	2	40	5	100
OldAdult	1	100	0	0	1	100
Total	27	84	5	16	32	100

(iv) ***Stature***

Stature could only be calculated for 10 individuals. Four of those were male (average 170cm) and three female (average 163cm). Table 5.71 shows the data. However, due to the small number for each sex it is difficult to say anything meaningful about the stature in this population. If the fragmentary nature of the collection had been known before data was collected, methods adapted for fragmentary long bones (e.g. Steele and McKern 1969) would have been considered to increase the amount of data collected for this indicator on this site.

Table 5.71: Average stature in Ghent

	M	?	F
No.	4	3	3
Average (cm)	170	164	163
SD	6.7		1.5

(v) ***Multiple indicators***

Due to the poor preservation of the skeletons in this population, the three main indicators were recorded in the same skeleton only 12 times (see Table 5.72). From those 12, cribra orbitalia, dental enamel hypoplasia and periosteal reaction were all present in only two skeletons. In seven skeletons only one indicator was recorded as present, for three of those only dental enamel hypoplasia was recorded, for the other four, periosteal reaction was recorded on the tibiae.

Table 5.72: Co-occurance of multiple indicators within one skeleton in Ghent (cribra orbitalia, dental enamel hypoplasia, perioseasteal reaction on the tibiae)

Number of indicators present	**No.**
3 indicators	2
2 indicators	2
1 indicator	7
No indicators	1
Total	**12**

5.4.4 Respiratory disease

(i) ***Maxillary Sinusitis***

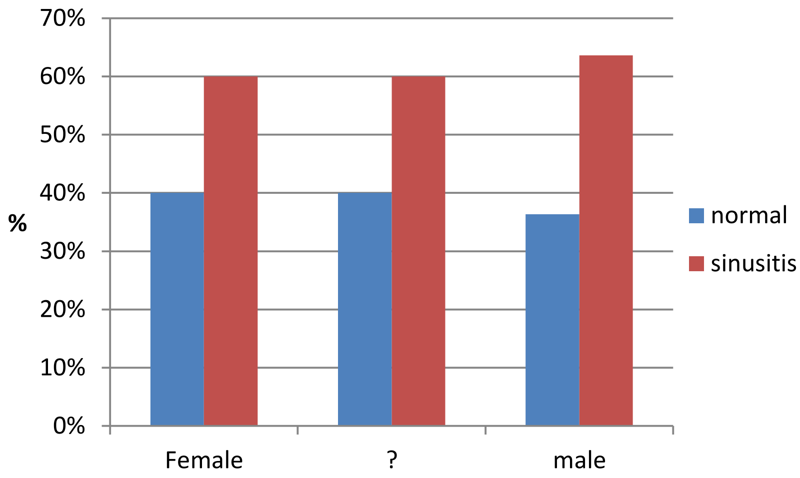
At least one sinus was preserved for recording in 36 individuals. Sinusitis was present in 22 (61%) of those (see Table 5.73). The endoscope was used for recording intact sinuses in six skeletons. Table 5.73 also shows that 56 sinuses were recorded for the 36 individuals. Just over half the sinuses (31/56, 55%) displayed sinusitis changes.

Table 5.73: CPR and TPR of maxillary sinusitis in Ghent

	Person		**Sinus**	
	No.	%	No.	%
No sinusitis	14	39	25	45
Sinusitis	22	61	31	55
Total	**36**	**100**	**56**	**100**

For 20 skeletons both sinuses were present: nine had sinusitis in both sinuses, seven had no sinusitis and four had sinusitis in either the left or right sinus. Figure 5.29 shows there was no significant difference ($\chi 2$: 0.035, p=0.851, df: 1) in maxillary sinusitis between males and females.

Figure 5.29: CPR of maxillary sinusitis and sex in Ghent



There was, however, a clear increase with increasing age-at-death (see Figure 5.30). This was not statistically significant (χ2: 5.226, p=0.073, df: 1, Fischer exact p=0.079). Over 80% (5/6) of young adults did not display any signs of maxillary sinusitis, but in the middle adult category 70% (7/10) already displayed signs of maxillary sinusitis. The oldest age category only contains one skeleton – which was recorded as having maxillary sinusitis (Table 5.74).

Figure 5.30: CPR of maxillary sinusitis and age categories in Ghent

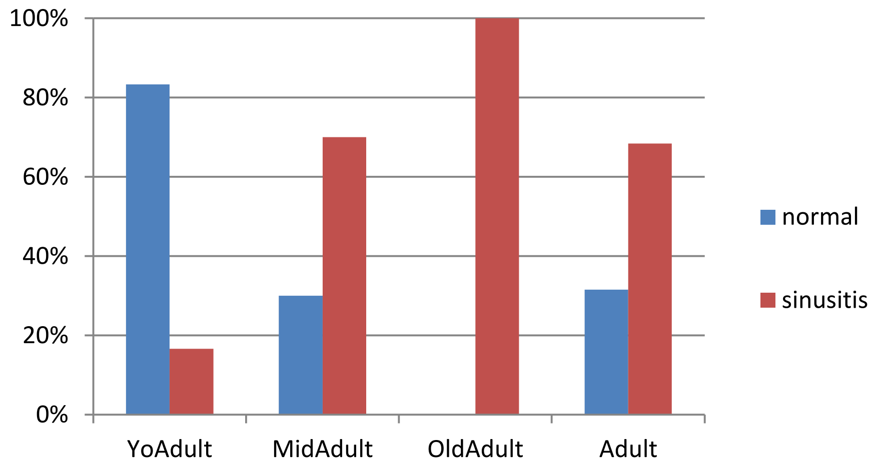


Table 5.74: Maxillary sinusitis and age categories in Ghent

	No sinusitis		**Sinusitis**		**Total**	
	No.	%	No.	%	No.	%
YoAdult	5	83	1	17	6	100
MidAdult	3	30	7	70	10	100
OldAdult	0	0	1	100	1	100
Adult	6	32	13	68	19	100
Total	**14**	**39**	**22**	**61**	**36**	**100**

There is no association ($\chi2$: 0.002, p=0.96, df: 1) between caries and maxillary sinusitis in this population (see Table 5.75). The three peri-apical lesions observed did not connect to the maxillary floor, and therefore a direct link cannot be established.

Table 5.75: Co-occurrence of caries and maxillary sinusitis in Ghent

	No sinusitis	**Sinusitis**	**total**
No caries	7	9	16
Caries	6	8	14
Total	**13**	**17**	**30**

(ii) ***Periosteal reaction of ribs***

Rib lesions could be recorded in 53 skeletons in Ghent. One had to be excluded as there was also evidence of trauma. Only five out of the remaining 52 (10%) have had rib lesions recorded (see Table 5.76). There was no difference between males and females. The numbers are too small to say anything meaningful about the distribution of frequency across the age categories. Out of the five individuals with rib lesions; three could not be assigned an age category (see Table 5.77).

Table 5.76: CPR of periosteal rib lesions and sex in Ghent

	Absent		Present		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**
M	12	23	2	4	14	27
F	26	50	3	6	29	56
?	9	17		0	9	17
Total	**47**	90	**5**	10	**52**	100

Table 5.77: CPR of periosteal rib lesions and age in Ghent

	Absent		Present		Total	
	No.	%	No.	%	No.	%
YoAdult	9	100	0	0	9	100
MidAdult	11	100	0	0	11	100
OldAdult	2	50	2	50	4	100
Adult	26	90	3	10	29	100
Total	**48**	**91**	**5**	**9**	**53**	**100**

5.5 Comparison of the three sites

5.5.1 Demography

(i) ***Sex estimation***

The differences in preservation of skeletons buried at the sites in Caen Canterbury, and Ghent were clearly visible in the data (see Table 5.78). While the number of skeletons for which sex could not be estimated was in single figures in Caen and Canterbury, in Ghent sex could not be estimated for 23% (see Figure 5.31) Table 5.79 shows that the variation in male to female ratios was minimal between the sites.

Table 5.78 Comparison of sex across the sites

	Caen		Canterbury		Ghent	
Sex	No.	%	No.	%	No.	%
M	26	26	21	21	17	20
?M	16	16	16	16	10	12
?	4	4	7	7	19	23
?F	27	27	31	31	16	19
F	27	27	25	25	21	25
Total	**100**	**100**	**100**	**100**	**83**	**100**

Figure 5.31: "Simplified" sex distribution across the sites

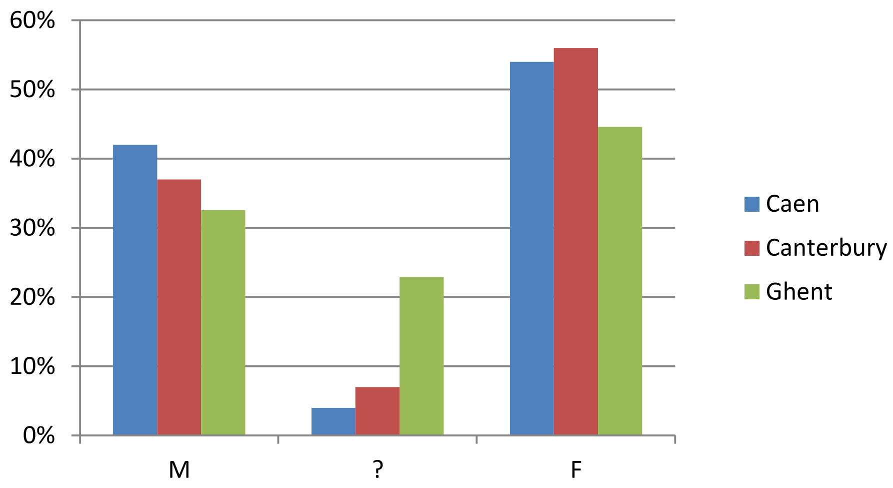


Table 5.79: Comparison of sex distribution across the sites

Site	M		F	
	No.	%	No.	%
Caen	42	44%	54	56%
Canterbury	37	40%	56	60%
Ghent	27	42%	37	58%

(ii) ***Age estimation***

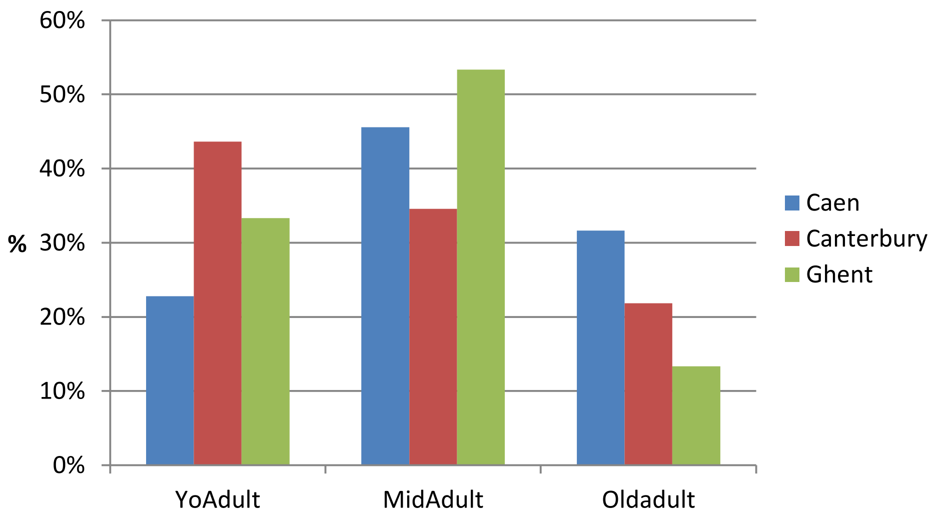
Age categories

The distribution across the age categories varies for the populations between the sites (see Table 5.80). Caen showed the largest proportion of skeletons in the oldest age category (32% - 18/79). Canterbury's frequencies in each category decreased with increasing age, and Ghent had its peak for the middle adult age category. This was especially visible when the 'adult' category was removed (see Figure 5.32).

Table 5.80: Age category distribution across the sites

	YoAdult		MidAdult		Oldadult		Adult		total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Caen	18	18	36	36	25	25	21	21	100	100
Canterbury	24	24	19	19	12	12	45	45	100	100
Ghent	10	12	16	19	4	5	53	64	83	100

Figure 5.32: Distribution of age categories across the sites



5.5.2 Dental disease

(i) ***Dental caries***

Dental caries lesions were recorded in 69% of the skeletons with teeth in Caen, but only in 41% in Ghent (see Figure 5.33). The difference between these populations was statistically significant (χ^2: 12.533 p=0.002, df: 2). Figure 5.34 shows this trend was also present in the number of teeth affected. In Caen 14.3% of the teeth of this population are affected, while only 5.5% are affected in Ghent (χ^2: 47.056, p=<0.001, df: 2).

Figure 5.33: CPR of caries across the sites

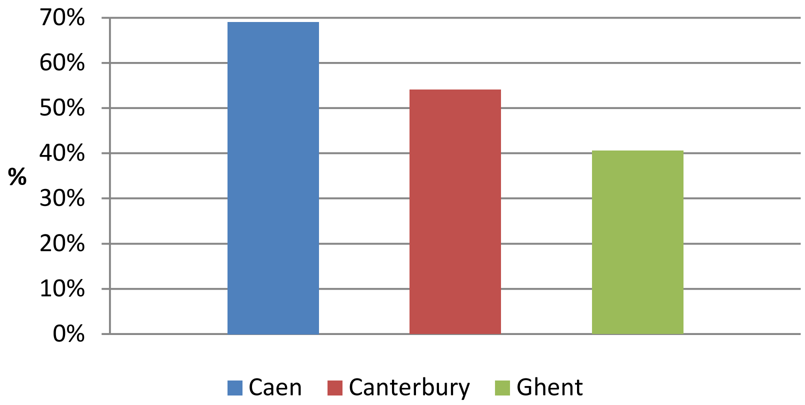
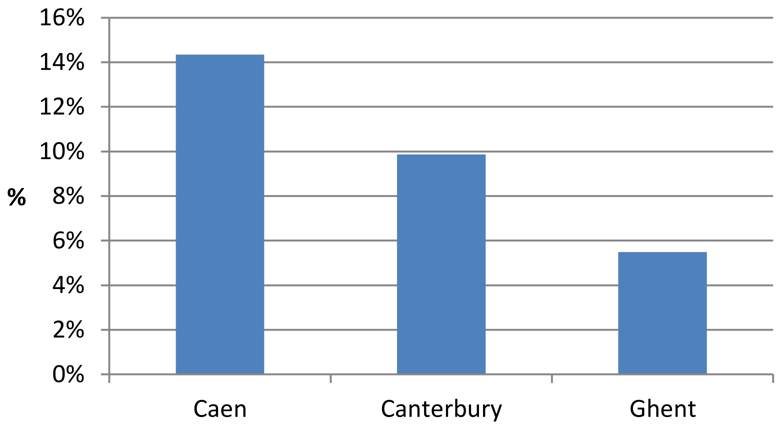


Figure 5.34: TPR of caries across the sites (% of teeth affected)



(ii) ***Peri-apical lesions***

Peri-apical lesions were uncommon in all populations. There were three individuals affected in Ghent, nine in Caen and 16 in Canterbury. Therefore these data need no further description.

5.5.3 Indicators of adaptation

(i) ***Dental enamel hypoplasia***

Dental enamel hypoplasia prevalence varied considerably between the sites (see Figure 5.35). In Canterbury, 61% of skeletons with dentitions available displayed dental enamel hypoplasia. In Ghent and Caen the levels were around 50%. This is not a statistically significant difference (χ^2: 2.6597 p=0.26452, df: 2).

Figure 5.35: CPR of DEH across the sites

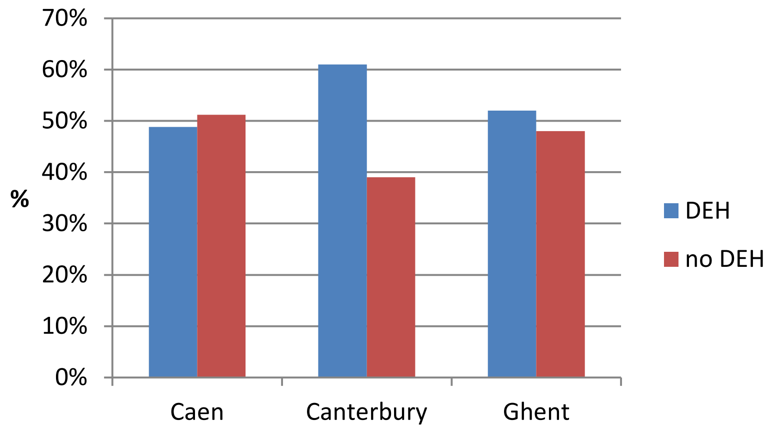


Figure 5.36 shows that a similar percentage of teeth were affected in individuals from Ghent (15%) and Caen (15%), while in Canterbury 21% of teeth were affected. Furthermore, people at Canterbury seem more severely affected, with 45% displaying multiple lines on teeth (see Figure 5.37). However, the canine teeth from people at Caen seem to be most severely affected, with 62% severely affected. People from Canterbury were the only ones with molars severely affected. The population buried in Ghent has the least number of teeth in the severe category.

Figure 5.36: TPR of DEH by tooth category across the sites (I: incisor, C: canine, PM: premolar, M: molar)

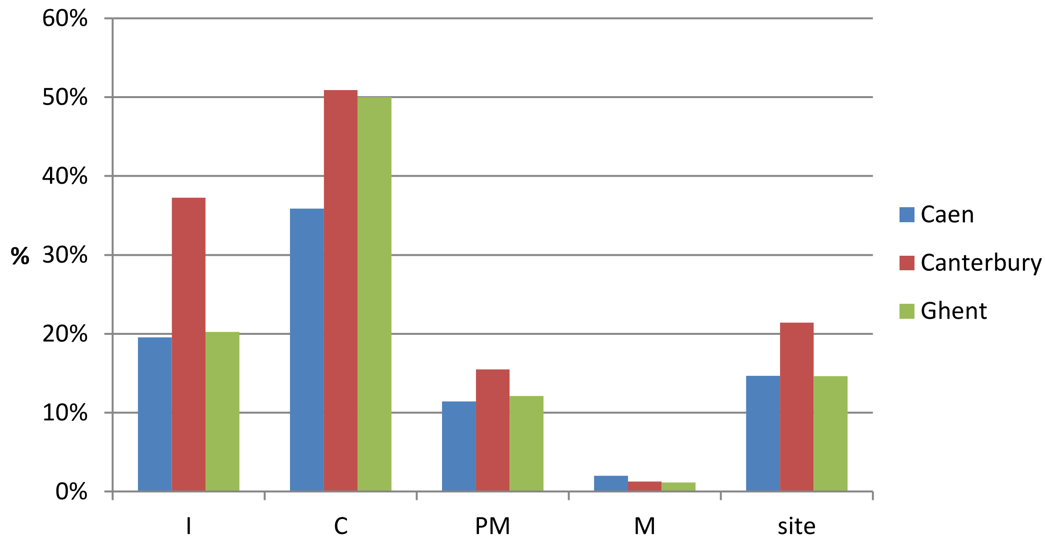
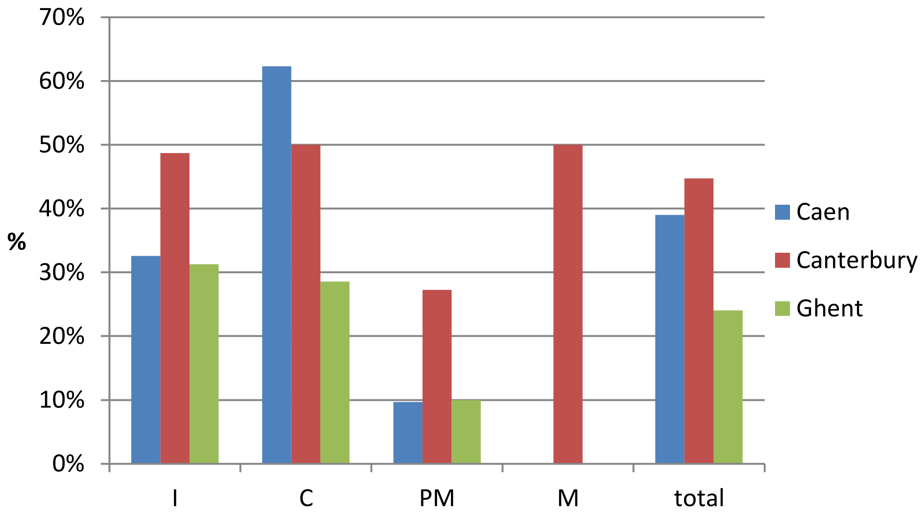


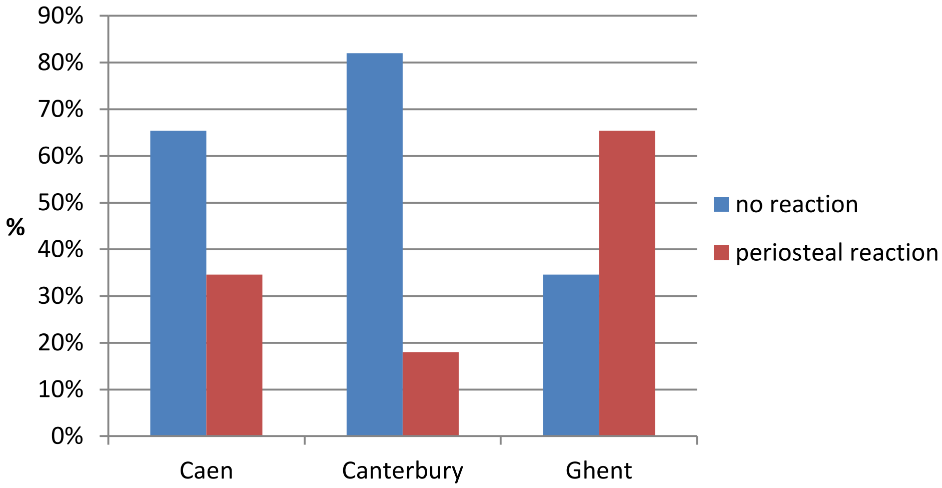
Figure 5.37:Severe DEH per tooth category across the sites (I: incisor, C: canine, PM: premolar, M: molar)



(ii) ***Periosteal reaction on the tibiae***

Ghent was the only site where periosteal reaction on tibiae is recorded in more than half the skeletons (9/26 – 65%) (see Figure 5.38). This difference was statistically significant (χ2: 18.503, p=>0.001, df: 2). Caen was also the only site where woven and mixed bone formation was present on the bones, while in Ghent and Canterbury only lamellar bone was recorded on the tibiae of people buried at those sites.

Figure 5.38 Periosteal reaction on the tibie across the sites.



(iii) ***Cribra orbitalia***

Cribra orbitalia was not common in people from any of the sites (see Table 5.81). In Caen and Ghent 16% of people were affected and in Canterbury only 7%. As would be expected, the small numbers this difference is not significant ($\chi2$: 3.195, p=0.202, df: 2).

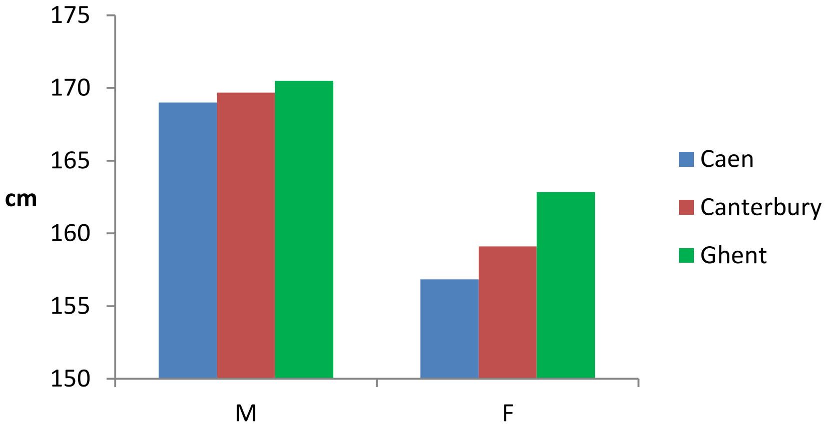
Table 5.81: CPR of cribra orbitalia across the sites

	Cribra		No cribra		Total
	No.	%	No.	%	No.
Caen	11	16	56	84	67
Canterbury	6	7	75	93	81
Ghent	5	16	27	84	32

(iv) ***Stature***

Figure 5.39 presents the male and female average stature across the sites. There was little variation in the average male stature, but there was a larger difference in female stature. Due to the small sample size in Ghent, a t-test was only conducted for females in Caen and Canterbury. The 2cm difference in average female stature between those two populations is not statistically significant (t: -1.35, p=0.18) and the smaller average stature for males and females in Caen can therefore only be described as a trend.

Figure 5.39: Average stature estimates across the sites



(v) ***Multiple indicators***

Table 5.82 shows that in all three sites around 60% of skeletons in which cribra orbitalia, dental enamel hypoplasia and cribra orbitalia could be recorded, only one lesion was recorded. In Canterbury this was predominantly dental enamel hypoplasia (23/27), while in Ghent this was equally divided between dental enamel hypoplasia (3/7) and periosteal reaction (4/7). In Caen, this was distributed even more with DEH the only indicator recorded in 11, cribra orbitalia in six and periosteal reaction in eight. In Caen and Canterbury no indicators were recorded in 24% and 21% respectively, while in Ghent this was much lower at 8%. However, the sample size in Ghent (12) is much smaller than in Caen (41) and Canterbury (43).

Table 5.82: Co-occurance of mutiple indicators (cribra orbitalia, dental enamel hypoplasia and periosteal reaction on the tibiae) in the same skeleton in the three sites.

	Caen		Canterbury		Ghent	
	No.	%	No.	%	No.	%
All	1	2	1	2	2	17
2 indicators	**5**	**12**	**6**	**14**	**2**	**17**
1 indicators	25	61	27	63	7	58
None	10	24	9	21	1	8
Total	**41**	**100**	**43**	**100**	**12**	**100**

For Caen and Canterbury, the presence of dental enamel hypoplasia was compared with the calculated stature. In Caen, no difference was observed in the average stature of skeletons with DEH and those without DEH (see 5.2.3 above). In Canterbury, on the other hand, there was a difference in average stature between those which displayed DEH and those who did not display lesions (see Table 5.83). This difference was only statistically significant for female stature (See section 5.3.3 above). There was no statistically significant difference between the sites in the average stature of the skeletons which displayed lesions or the skeletons which did not display lesions. However, the SSD in Caen was greater in those displaying lesions (1.08) than those without lesions (1.06).

Table 5.83: Average stature (cm) of males and females with and without DEH in Caen and Canterbury and their respective sexual dimporhism ratio (SSD)

	DEH			NO DEH		
	male	female	SSD ratio	male	female	SSD ratio
Caen	170	157	1.08	168	158	1.06
Canterbury	167	157	1.06	171	161	1.06

5.5.4 Respiratory disease

(i) ***Maxillary sinusitis***

Maxillary sinusitis was common in the people buried at all three sites. Nevertheless, there are variations between the sites (see Tables 5.84 and 5.85). In Caen 71% of people were affected, while in Canterbury and Ghent respectively 64% and 61% were affected. These differences were not statistically significant (χ^2: 1.076, p=0.255, df: 2). There was no difference in maxillary sinusitis prevalence between the sexes at any of the sites. In all sites the prevalence of maxillary sinusitis increased with age.

Table 5.84: CPR of maxillary sinusitis across the sites

	No sinusitis		Sinusitis		Total	
	No.	%	No.	%	No.	%
Caen	16	29	39	71	55	100
Canterbury	23	36	41	64	64	100
Ghent	14	39	22	61	36	100

Table 5.85: TPR of maxillary sinusitis across the sites

	No sinusitis		Sinusitis		Total
	No.	%	No.	%	No.
Caen	28	31	62	69	90
Canterbury	35	36	61	64	96
Ghent	25	45	31	55	56

(ii) ***Periosteal reaction on the ribs***

Periosteal reaction was equally common in Caen and Canterbury, with 63% of individuals affected at each site (see Table 5.86). In Ghent only five individuals were affected (10%). The difference between Ghent on the one hand and Caen and Canterbury on the other hand was statistically significant ($\chi 2$: 29.099, p=<.001, df: 2).

Table 5.86: CPR of periosteal reaction on the ribs across the sites.

	Absent		**Present**		**Total**
	No.	%	No.	%	No.
Caen	32	37	54	63	86
Canterbury	33	36	56	63	89
Ghent	48	90	5	10	52

5.6 Summary

This chapter has described the data and analysis undertaken in this research. It has shown that there are very few statistically significant differences between Caen, Canterbury and Ghent. The only statistical differences are: Ghent has higher levels of periosteal reaction on the tibia and lower levels of periosteal reaction on the ribs. The following chapter will aim to interpret these results drawing on the information discussed in Chapter 2 and 3.

Chapter 6 Discussion

The main aim of this thesis was to provide a comparative picture of late medieval urban health in culturally and geographically closely related regions of North-West Europe. Chapter 2 has shown that even today rapidly developing towns and cities struggle with providing a healthy urban environment. The themes identified in this chapter were then explored for late medieval rapidly developing towns in NW Europe and especially Caen, Canterbury and Ghent in Chapter 3. This led to the following hypotheses and questions:

- Poor sanitation, frequent warfare, economic collapse and the plague had a negative impact on health in Caen.
- The relative lack of industry in Canterbury may have had a positive impact on the health of its inhabitants.
- Early industrial specialisation and the suburban nature of the living environment in Ghent led to indoor and outdoor pollution which negatively impacted health

- Are there any demographic differences in health within and between the populations?
- Did poor sanitary conditions lead to increased levels of skeletal indicators (dental enamel hypoplasia, cribra orbitalia, periosteal reaction on the tibiae and a shorter stature)?
- Did poor air quality lead to high levels of respiratory disease (maxillary sinusitis and periosteal rib lesions)?
- Do these results reflect the effect of socio-economic status rather than the effects of urbanisation? For example, in Canterbury the cemetery population from the cemetery of St. Gregory was a combination of parishioners and inmates of St. John's hospital for the poor and infirm (Hicks and Hicks, 2001).

In order to consider these hypotheses and answer these questions, the first half of this chapter considers the results presented in the previous chapter (Chapter 5) seperately. The second half of the chapter then integrates the skeletal evidence with historical and archaeological evidence. Before discussing the results, the limitations of this research are discussed.

6.1 Limitations of the research

The same limitations that apply to any bioarchaeological study also apply to this one. Many of the general issues have been outlined by Wood et al (1992) in 'the osteological paradox' and 'Counting the death' by Waldron (1994), but will be discussed here in relation to this study in particular.

6.1.1 Selection pressures and sampling strategy

The prevalence of pathological lesions recorded in this study has likely been influenced by the sampling strategy employed. In Ghent, all adults from the site (83) were included in this research. On the other hand, in Canterbury and Caen only 100 skeletons from each site were selected from much larger numbers of excavated individuals. Even if all skeletons available had been analysed, other factors, ranging from the characteristics of the people buried in the cemetery to their post-excavation treatment and storage of the skeletal remains, would have affected the final results. Waldron (1994) describes the different selection pressures that apply at every stage and ultimately affect the skeletal sample in any study.

The first selection pressure applies at the time of burial. In the late medieval period most burials in Europe were associated with the Catholic Church (Gilchrist and Sloane, 2005). Often burial was within the parish in which the person lived, but there were exceptions. Some people may have been, or were, excluded from the normative burial rite on religious grounds (for example, people who had committed suicide, or who had specific diseases like leprosy, or murderers) (Roberts et al., 2002; Gilchrist and Sloane, 2005). The cemeteries of Caen, Canterbury and Ghent were used as parish cemeteries (Marin et al., 1991; Hicks and Hicks, 2001; Bru et al., 2010). However, the cemetery of St. Gregory's in Canterbury was also used to bury the inmates from the nearby St. John's hospital for the poor and infirm (Hicks and Hicks, 2001) and this will have affected the results. It is not possible to determine whether the skeletons included in this research had been parishioners or inmates from the hospital.

Furthermore, there may have been spatial differences within the cemetery. For example, age and sex specific zones have been described within a medieval Swedish cemetery (Kjellström et al., 2005). At the time of excavation, many projects may only excavate part of a cemetery in advance of redevelopment of a site and, if zoning is present, some subgroups within the population may not be excavated and would therefore not be represented in subsequent analyses (Waldron, 1994). Even if the entire cemetery is excavated, the recovered skeletal material will only be a fraction (often unknown) of those that lived and were buried in the cemetery and, due to how the cemetery was spatially organised, this may not reflect the cross section of the population as a whole (Waldron, 1994). To limit the impact this bias has on this study, skeletons from across the site were selected where possible.

In the late medieval period, it was common in NW Europe to disturb graves to make place for new ones (Gilchrist and Sloane, 2005), as a consequence many skeletons are incomplete. Furthermore, preservation is affected by the chemical composition of the soil. Not all bones are affected equally and pathology can lead to faster decomposition of the bone (Henderson, 1987; Pinhasi and Bourbou, 2008; Turner-Walker, 2008). In this study skeletons were selected based on their preservation and the number of indicators that could be recorded (see Chapter 4). However, including or excluding skeletons that are only partially present may affect the prevalence calculated (Waldron, 2009). The prevalence rates calculated in this research are on the individual level (crude prevalence rate) and on the level of the element (true prevalence rate) (see Chapter 5 for more detail).

In this study a maximum of 100 skeletons were analysed from each site. In Caen and Canterbury many more skeletons were available for study, but could not be analysed due to time constraints. The selection of another 100 skeletons would likely have resulted in different prevalence rates. If a larger number of skeletons had been included, it would have been possible to undertake more robust statistical analysis, especially in situations that involve the division of the sample in subcategories (for example sex) as the sample size in each subcategory would have been larger and thus more likely to be representative of the underlying population.

6.1.2 Heterogeneity within and between the cemeteries

In this research, the skeletons have been treated as one homogenous group. However, the populations investigated here would not have remained static throughout the time that the cemetery was in use. First, a momentous change can be identified in late medieval NW Europe. The climate changes from a mild, stable climate from the 9th to 13th century to a much more unpredictable, colder climate from the 14th to 17th century (Lehner, 2012), which led to crop failures. Furthermore, the plague arrived in NW Europe in 1348, with devastating effects on the population. The excess death associated with the Black Death means that sometimes dedicated cemeteries were created to deal with the excess mortality, for example East Smithlfield in London (Grainger, 2008). A lack of stratigraphy and phasing in a late medieval parish cemetery means it is usually not possible to identify such peaks in disease prevalence. For the site of St. Mary Spital, London it was possible to use stratigraphy, radiocarbon dating, and statistics for phasing the cemetery and thus identify peaks in disease prevalence (Connell et al., 2012). For example, the prevalence of DEH in males and females from St Mary Spital varied between the different phases (Connell et al., 2012) (see section 6.3.2 below). Such phasing was not available for the cemeteries in Ghent, Canterbury and Caen (see Chapter 4).

Migration was important in late medieval towns in NW Europe to maintain and increase population levels and this was the case in Caen, Canterbury and Ghent (see Chapter 3). Some of the indicators used in this research do, however, reflect childhood conditions. If people migrate in adulthood (e.g. looking for work), the skeletal lesions still reflect the area they grew up and not necessarily the area they were buried. It is not possible to identify migrants within the constraints of this project.

Also, not everyone within the population would have been at equal risk of developing an illness or lesions (Waldron, 2009). For example, malnutrition and undernutrition reduces the effectiveness of the immune system. As a consequence, it increases the risk of developing a disease and the disease outcomes tend to be worse than in healthy individuals (Prüss-Üstün, 2006).

6.1.3 Methods

The selection of pathological lesions recorded in this study aimed to best reflect the health of the populations analysed. Indicators of adaptation used as a proxy for population “health”, and evidence for respiratory disease as a proxy for poor air quality. Due to the limited number of ways in which bone can respond (additional bone growth or bone resorption), each indicator has a complex aetiology and it is not possible to understand the aetiology of indicators in individual skeletons and therefore how much each factor has impacted on the health of the populations investigated here. The different aetiological factors affecting each indicator used in this research has been discussed in Chapter 2 and will be taken into account in the discussion of the results below.

The selection of indicators in this research was limited due to constraints on time and equipment. It is possible that the indicators recorded do not accurately reflect the health of population, and that other indicators would have provided more obvious differences in prevalence rates between the three population (Robb et al., 2001).

6.1.4 Dating of the sites

The dates of the sites have been discussed in detail in Chapter 4. The date of the cemetery from Canterbury falls directly within the medieval period. However, both the cemetery in Caen and Ghent were in use from the 12th century until the 18th century. In Ghent, the post-medieval layer may have been removed at a later date to level the area (Laleman, pers. Comm.). A typology of the graves in Caen suggests a large proportion of the skeletons used in this study may be post-medieval (16th-18th centuries). Again, there is some doubt about the reliability of this dating (see Chapter 4). For the purpose of this thesis and comparability with the other sites they are interpreted in light of the late medieval period.

Post-medieval archaeology is still trying to find its research identity in many parts of Continental Europe (Gaimster, 2009; Herremans and De Clercq, 2013). In contrast, in the UK, post-medieval archaeology has a much longer history as a separate entity (Egan, 2009). In Flanders, Early Modern layers are still considered of less interest than older layers, but interest has been growing in the last decade (Herremans and De Clercq, 2013). When studied, the Post-Medieval Period is often seen as an extension to the medieval period or as part of urban archaeology (Gaimster, 2009). The development of rescue archaeology for the last 30 years has, however, created vast amounts of post-medieval artefacts across Europe, but they are poorly studied. This has been referred to as the '*embarrassment of riches*' (Gaimster, 2009). In the UK the study of post-medieval funerary archaeology and the study of cemeteries has been much more established (Roberts and Cox, 2003; Gaimster, 2009) and much could be learnt if this kind of research were extended across Continental Europe.

6.1.5 Comparative sites

The comparison of the data from this study with previously studied skeletal remains in NW Europe was fraught with difficulty. Firstly, data collection strategies for comparative sites may have varied between different studies as data may have been collected for different purposes. Even though standards have previously been published (Buikstra and Ubelaker, 1994; Brickley and McKinley, 2004), they do not cover every aspect of the study here. For example, the full extent of recording of periosteal rib lesions has not been consistent in bioarchaeology. Some studies include "nodules" on ribs, while others ignore them (Nicklisch et al., 2012), and some scholars do not record rib lesions at all, thus meaning that comparative data are not available. This will be discussed in more detail below under future work. Another example is the use of Breitinger (1938) for stature calculation in some of the studies from The Netherlands, rather than Trotter (1970), as in this study.

A lack of published or accessible unpublished palaeopathological research in Belgium and northern France meant that there were only a limited number of comparative sites available from these areas, thus limiting interpretation within a regional framework.

Lastly, it has been discussed above that crude prevalence rate can be a poor representation of the underlying population. However, as this is the most commonly provided prevalence rate in skeletal reports, it has been used most often in this discussion.

6.2 Comparison of skeletal indicators

In this section the results from this study are compared with data from other studies in northern France, England and The Low Countries. First, the details of the comparative sites are provided for each region separately. The actual data is then discussed for NW Europe as a whole. In the subsequent section these results are then contextualised using other sources of information. First the comparative sites chosen for each region are presented.

6.2.1 Comparative sites

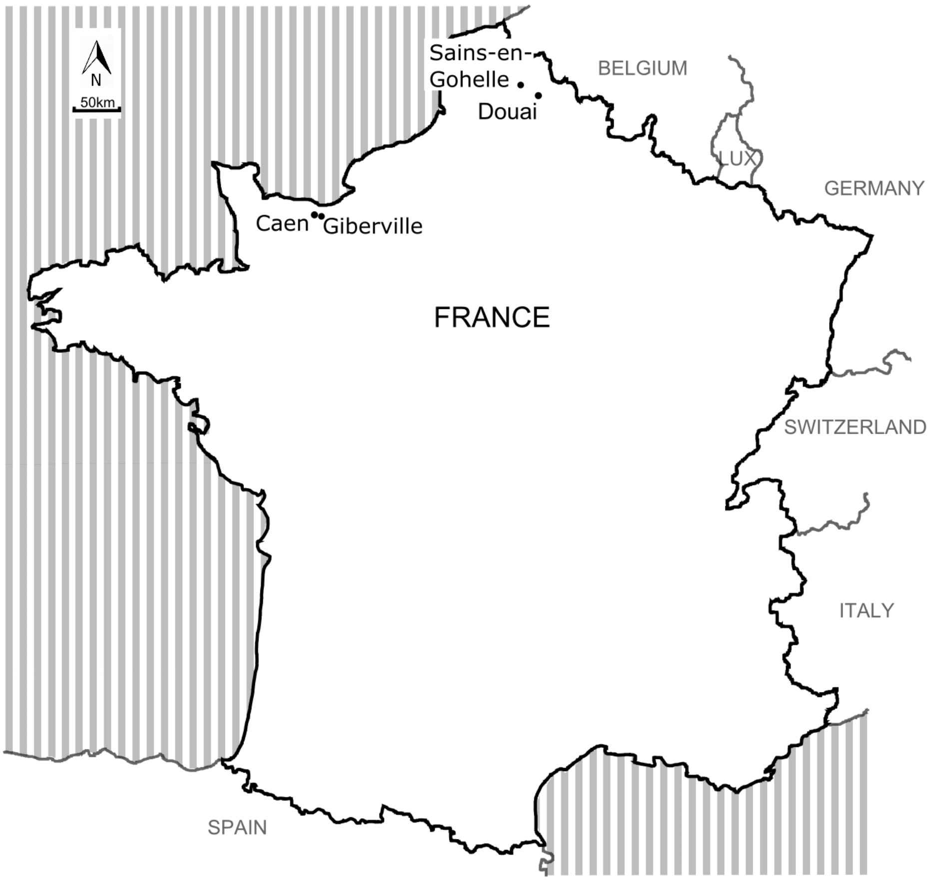
(i) ***Northern France***

Only limited skeletal data were available from northern France for this period with which to compare the data from Caen (see Table 6.1). The comparative data from St. Amé and St. Jacques in Douai were kindly provided by Benoit Bertrand and Sophie Vatteoni from *La Communauté d'Agglomération du Douaisis (CAD),* in advance of publication. St Jacques was one of the largest parishes in Douai and represents the wider population (Vatteoni pers. comm.). St. Amé, on the other hand, was a small parish linked with a church, and parishioners as well as cannons and the elite were buried here (Demolon et al., 2013). The locations of these comparative sites are shown in Figure 6.1.

Table 6.1: Comparative sites in France

Site name	Type	No. skeletons	Period	References
St. Jacques, Douai	urban	1000+	16th-18th century	pers comm
St. Amé, Douai	urban	1000+	16th-18th century	pers comm
Sains-en-Gohelle	rural	417	8th-18th century	Beauval et al. 2012
Darnétal, Caen	**urban**	**100**	**12th-18th century**	**this research**
Saint-Martin of Giberville	rural	130	7-14th century	Alduc-Le Bagousse 1983, 1984

Figure 6.1: Location of comparative sites in France



(ii) ***England***

Canterbury was a busy market town with a strong focus on the pilgrim trade in the late medieval period (Méar-Coulstock, 2010; Rawcliffe, 2013). This section explores if the relatively low level of industry and the high level of transient migration had an impact on the health of the inhabitants. Furthermore, the original population contributing to the cemetery of St. Gregory’s Priory was a combination of the Northgate parish as well as people who were from St. John’s hospital for the poor and infirm (Hicks and Hicks, 2001; Dawson, 2014). A comparison with contemporary sites from England aims to infer the potential impact of the hospital population on the inferences made in this study. Figure 6.2 shows the locations of the sites that were used as comparators for Canterbury, while Table 6.2 provides some additional information about these sites. In the tables, St Joseph and Mary Magdalene Hospital, Chichester is abbreviated as “hospital, Chichester”

Table 6.2: Sites used in comparison to St. Gregory, Canterbury

Site Name	Type	Period	No. Skeleton	References
Blackfriars, Ipswich	friary/ urban	13-16th century	250	Mays 1991
Hospital, Chichester	hospital	12-16th century	306	Magilton et al 2008
Fishergate House, York	urban	11-16th century	244	Holst 2005
Guildhall Yard East, London	urban	11-13th century	40	Bernofsky 2010
St. Andrew Fishergate, York	urban/ priory	11-16th century	402	Stroud and Kemp 1993
St. Gregory's Priory, Canterbury	**urban/ priory**	**11-16th century**	**100**	**this research**
St. Helen-on-the-Walls, York	urban	12-16th century	1037	Lewis et al. 1995, Grauer 1989
St. Margaret, Norwich	urban	12-15th century	413	Stirland 2009
St. Mary Graces, London	urban	14-15th century	378	Bernofsky 2010
St. Mary Spital, London	hospital/ priory	11-16th century	10,516	Connell et al 2012
St. Nicholas Shambles, London	urban	11-12th century	234	Bernofsky 2010, White 1988
Wharram Percy	Rural	10^{h} – 19^{th} century	360	Mays et al 2007, Lewis et al 1995a

Figure 6.2: Comparative sites in England

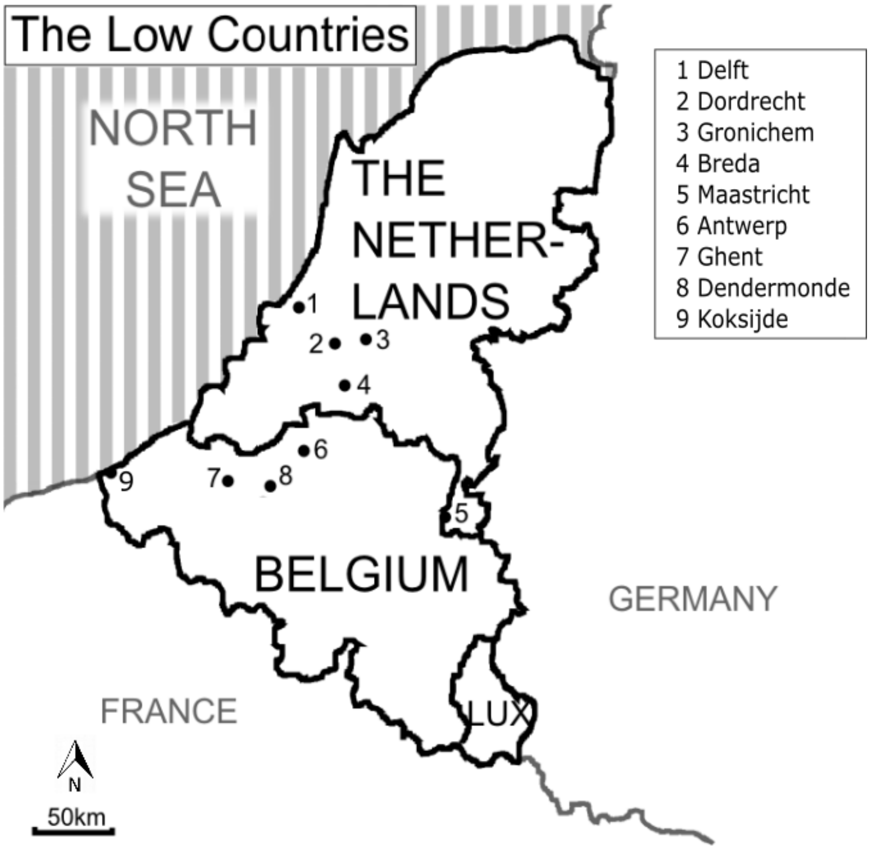
(iii) ***Low Countries***

Comparative bioarchaeological data from Flanders/ Belgium is scarce and, as a result, data from sites in the Low Countries were included as comparators. Figure 6.3 indicates that the Low Countries include the current countries of Belgium, The Netherlands and Luxembourg. It also shows the location of the sites that have been included as comparators for Ghent. Table 6.3 provides more information on these sites.

Table 6.3: Sites used for comparison with Ghent Sint Pieter

Site name	Type	Period	References
Augustijnen, Antwerpen	urban	16th-18th century	Bellens and Vandenbruane 2006
Beguines, Breda	monastic	13th-16th century	Rijpma and Maat 2005
Oude en Nieuwe Gasthuis, Delft	urban	13th-16th century	Maat 2003
Dendermonde	plague cemetery	16th century	Gueguen 2012
Minderbroeders, Dordrecht	monastic	13th-16th century	Maat et al 1998
St. Veerle, Ghent	urban	13th-16th century	Gernay 2009
Gronichem	urban	15th-16th century	Maat 2003
Ter Duinen, Koksijde	monastic	12th-15th century	Bosmans 2013, Polet et al. 2000
Maastricht	monastic	11th-16th century	Maat 2003
Nunnery, Maastricht	monastic	13th-17th century	Panhuysen et al. 1997

Figure 6.3: location of the sites in the Low Countries used as comparison with Ghent.



6.2.2 Skeletal indicators of adaptation

(i) ***Dental Enamel Hypoplasia (DEH)***

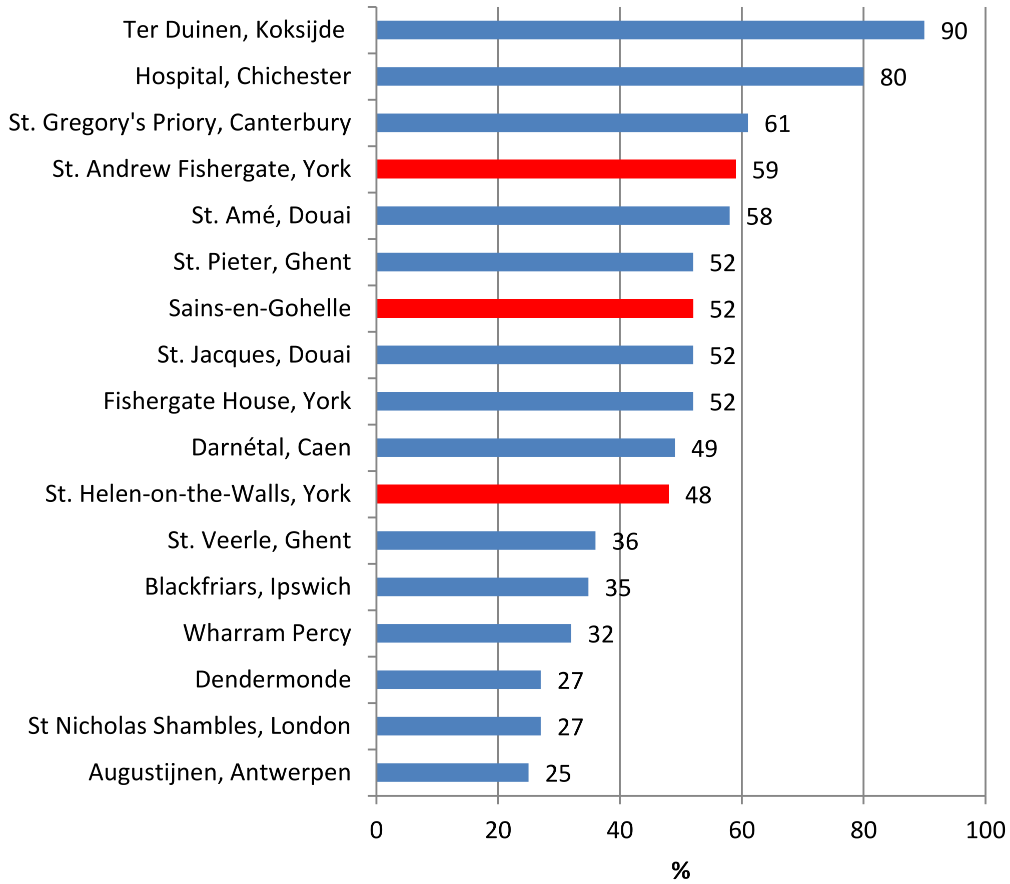
The crude prevalence rate of DEH was very similar for individuals from Caen (49%) and Ghent (52%), with a higher prevalence rate in Canterbury (61%). This pattern is also observed when comparing the true prevalence rates: 15% of teeth were affected for both Caen and Ghent, but 21% of teeth were affected in Canterbury. Nevertheless, the difference between the sites was not statistically significant (χ^2: 2.6597 p=0.26452, df: 2). These results do relate differently to the data available in each country (see Figure 6.4).

The prevalence of DEH was relatively low in Caen (49%) compared to skeletal data from the two urban sites in Douai (52-58%) and a rural site from Sains-en-Gohelle (58%) (Beauval et al., 2012). The prevalence of DEH recorded in Canterbury (61%) is high in comparison to contemporary sites from this region, with only the hospital population at Chichester (80%) reporting a higher prevalence (Magilton et al., 2008).

The data from St. Gregory's (61%) is, however, more comparable to prevalence rates reported for two populations from York: St. Andrew Fishergate (59%) and Fishergate House (52%) (Stroud and Kemp, 1993; Holst, 2005). In Ghent, DEH was recorded in just over half the population of Ghent St. Pieter (52%). This is much higher than the more centrally located Ghent St. Veerle (32%). The latter was associated with the Flemish Count and therefore the people buried there are likely the elite (van Werveke and Verhulst, 1960). Even so, the prevalence Ghent St. Pieter was higher than at Antwerp (25%) and Dendermonde (27%) (Bellens and Vandenbruaene, 2006; Guegen, 2012). However, the prevalence rate was still much lower than the 90% reported for the monastic site of Koksijde (Bosmans, 2013).

Looking at the severity of DEH (multiple defects vs one defect per tooth), Caen and Canterbury showed similar results with 43% and 45% with DEH showing multiple lesions respectively. On the other hand, in Ghent only approximately a quarter of the teeth (24%) with DEH were recorded as severe. This could indicate that Ghent was affected less by stress. On the other hand, this could indicate that people in Caen and Canterbury were more likely to survive periods of hardship. These possible interpretations will be explored below using historical and archaeological evidence.

Figure 6.4: CPR of DEH in NW Europe



(ii) ***Stature***

Comparing male and female stature in Caen, Canterbury and Ghent has not revealed any statistically significant differences. Average male stature was 169cm in Caen, 170cm in Canterbury, and 171cm in Ghent. A clearer difference was seen in average female stature with 156cm in Caen, 158cm in Canterbury and 163cm in Ghent. The results from Ghent are, however, based on very small sample sizes, with only four males and three females with complete long bones. The results from this site may therefore not be representative of the underlying population. Furthermore, they were not taken into account in statistical analyses of this indicator. The 2cm difference in average female stature was not statistically significant (t: -1.35, p=0.18),

When these results are put in a regional framework, then it is clear that great variability in average stature estimates have been reported in NW Europe (see Figure 6.5 and Figure 6.6). In England, results from many urban sites are available, but in France and the Low Countries data from other types of sites were included. In England, the average urban stature for males varies between 169cm and 173cm and between 156 cm and 161cm for females. The inclusion of two rural sites in northern

France suggests there could have been urban-rural differences. The stature estimates from Sains-en-Gohelle (173cm for males and 158cm for females) (Beauval et al., 2012) were much taller than the estimates from Caen and Douai. On the other hand, the results from Saint Martin, Giberville are more comparable with the urban populations. The average male stature is the same for this site and St Jacques in Douai (170cm) and females in Saint Martin are actually one centimetre shorter than those from St Jacques (156cm and 157cm respectively) and the shortest reported. In England, average stature at rural Wharram Percy is comparable to Saint Martin, with a small male average stature estimate (169cm) and a female average stature comparable to urban sites (158cm).

Adult stature is determined by both genetic and environmental factors (see chapter 2). If males are worse affected by stress, then a smaller sexual dimorphism ratio would be expected. Having calculated the sexual stature dimorphism for all sites with male and female statures (see Table 6.4), it is clear that despite differences between the populations, the sexual dimorphism in most of these sites is comparable at 1.07 or 1.08. When environmental stress affects growth during childhood, maturation can be delayed (see Chapter 2). If this is the case, the adult stature in these populations would not accurately reflect underlying environmental stress.

In Caen and Canterbury sample sizes allowed the comparison of average stature estimates with the presence of DEH. In Caen there was no statistically significant difference in average stature between those with DEH and those without defects in either males or females. In Canterbury, both males and females with dental defects were on average 4cm smaller than those without defects. This difference is, however, only statistically significant for females (males: t: -1.4082, p=0.18; females: t: -4.015, p= <0.01). This also translates in differences in sexual stature dimorphism. In Caen, the sexual dimorphism ratio is 1.06 for both the groups with and without DEH. On the other hand, in Canterbury the ratio is 1.06 in those without DEH and 1.08 in those with DEH. It is possible that conditions in Caen were more conducive to catch-up growth before reaching adult stature. However, as the average stature of males and females in Caen is relatively small within a European context, it is possible that the entire population was affected by stressors leading to reduced stature but that only 49% of people were at a critical time in the dental development for lesions to develop.

Figure 6.5: Male average stature in NW Europe (* stature calculated using Breitinger's formula.)

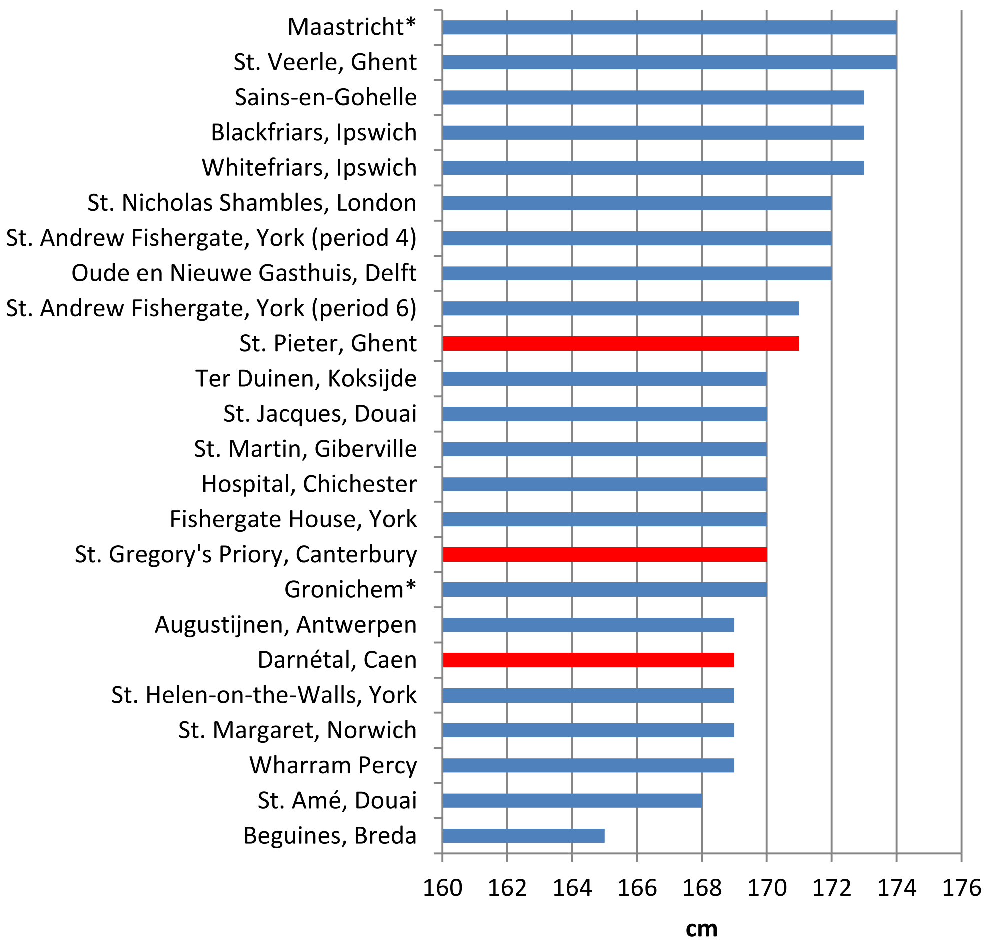


Figure 6.6: Female average stature in NW Europe

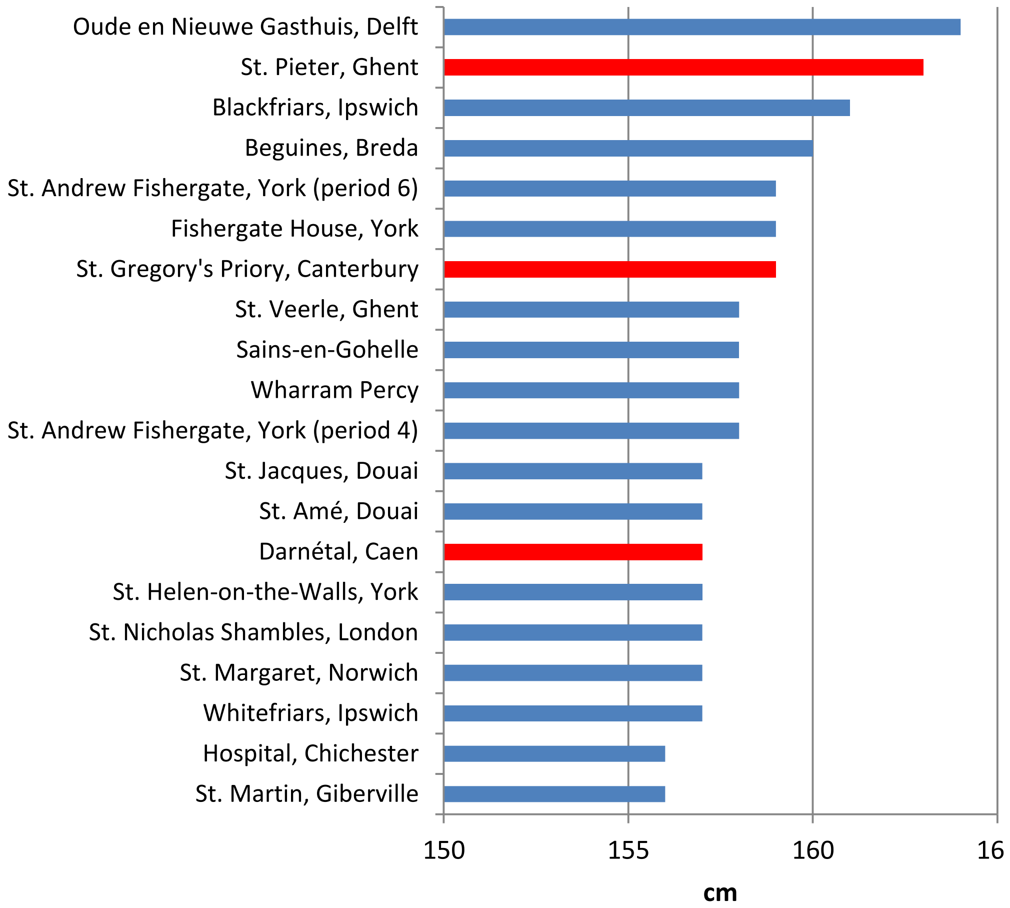


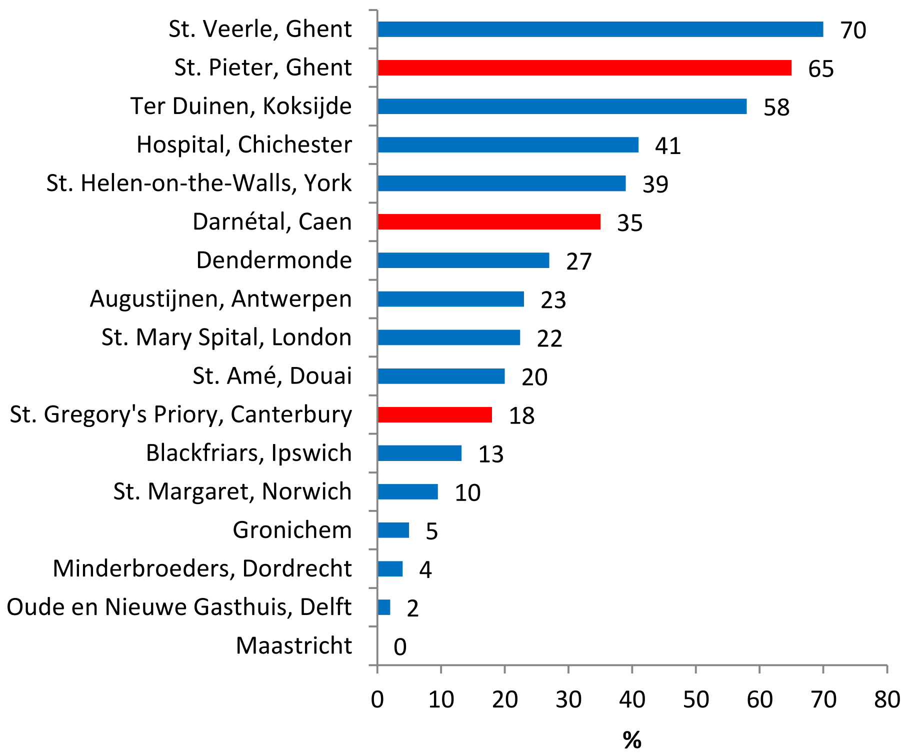
Table 6.4: Sexual stature dimorphism in NW Europe

site	male	female	ratio
St. Gregory's Canterbury	170	159	1.07
Wharram Percy	169	158	1.07
St. Amé, Douai	168	157	1.07
Blackfriars, Ipswich	173	161	1.07
Fishergate House, York	171	159	1.08
Darnétal, Caen	169	157	1.08
St. Margaret, Norwich	169	157	1.08
St. Helen-on-the-Walls	169	157	1.08
St. Jaques, Douai	170	157	1.08
Saint Martin, Giberville	170	156	1.09
Sains-en-Gohelle	173	158	1.09
St. Veerle, Ghent	174	158	1.10

(iii) *Non-specific periosteal reaction on the tibiae*

Figure 6.7 shows that the prevalence of non-specific periosteal reaction in late medieval NW Europe is quite variable. Urban sites from the Low Countries are especially low (0-27%) (Maat et al., 1998; Maat, 2003). The parish cemeteries of Norwich (10%) and Ipswich (13%) display relatively low levels of lesions (Mays, 1991; Stirland, 2009). On the other hand, the poor parish in York (St Helen-on-the-Walls) and the hospital population in Chichester display much higher prevalence rates (39% and 41%, respectively) (Grauer, 1989; Magilton et al., 2008). At the high end there are Koksijde (58%) and Ghent (70%) (Guegen 2012, Gernay 2009). The prevalence rates of Caen (35%) and Canterbury (18%) fall within the middle of that range, while Ghent's prevalence rate (65%) is high. A comparable prevalence rate has been reported for St. Veerle (70%) in Ghent (Gernay 2009).

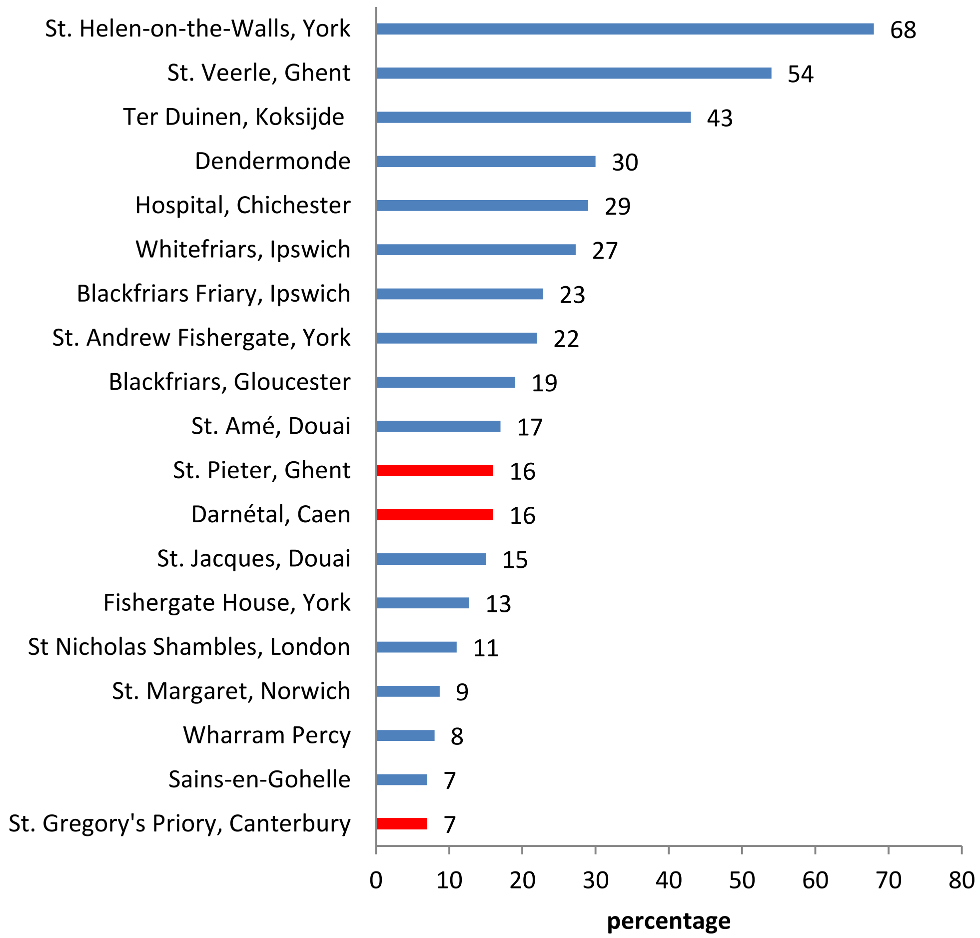
Figure 6.7: CPR of non-specific periosteal reaction



(i) ***Cribra orbitalia***

Cribra orbitalia was recorded in 16% of the skeletons analysed from Caen and Ghent, while a lower prevalence rate was recorded for Canterbury (7%). Figure 6.8 shows that the crude prevalence rate of Caen is comparable with the urban populations from Douai, with a 15% prevalence rate at St. Jacques and 17% at St. Amé. Norwich and Fishergate House, York were similarly low, with prevalence rates of 9% and 13%, respectively (Holst, 2005; Stirland, 2009). On the other side of the spectrum the poor parish in York (St Helen-on-the Walls) had exceptionally high levels of cribra orbitalia (68%) (Grauer, 1989). The next highest level in England was for the hospital population of Chichester (29%) (Magilton et al., 2008). Forty-three percent was, however, reported for the monastic site of Ten Duinen in Koksijde. The prevalence of cribra orbitalia recorded for St. Gregory's (7%) in this study was the lowest for late medieval sites from England (see Figure 6.7) and is most comparable to the rural site of Sains-en-Gohelle in France (7%) and Wharram Percy in England (8%) (Beauval et al., 2012; Mays et al., 2007). Dawson's (2014) study of non-adult skeletons from St. Gregory's shows a much higher prevalence of cribra orbitalia of 46% (72/155), and it is therefore likely that many of those affected did not survive into adulthood or that their lesions healed. The 16% prevalence rate recorded for individuals buried at Ghent St Pieter was the lowest recorded in the Low Countries, with other sites varying between 30% and 54%, but does not stand out in a wider context. Previous studies have found a decrease in the prevalence of cribra orbitalia with increased population density (Gowland and Redfern, 2010; Ulrich-Bochslerr et al., 2011). It is therefore surprising that the relatively rural suburb of St Pieter in Ghent would have the lowest prevalence rate within its region.

Figure 6.8: CPR of cribra orbitalia in NW Europe



6.2.3 Respiratory disease

Respiratory disease overall was common in all three populations. Maxillary sinusitis was most prevalent in Caen (71%), followed by Canterbury (64%) and Ghent (61%). The 10% difference between Caen, and Canterbury and Ghent is not statistically significant (t: -1.35, p=0.18). No comparative data was available from the Low Countries or northern France apart from Maastricht. Comparing the results from this study with evidence from Maastricht and England shows that the prevalence rates in this study are relatively high, but not exceptional with many reported prevalence rates in a similar range (58-63%). Then there are a few sites in the 40-50% range, such as Maastricht at 44% (Panhuysen et al., 1997). Notably, some sites in London show much lower prevalence rates with the lowest rates reported for St Nicholas Shambles (12%) and St Mary Spital (2%). The great variability in York is also striking with St Helen-on-the-Walls having a high prevalence (63%), but only 34% affected in Fishergate House. There were no statistically significant demographic differences in their prevalence in any of the sites. The prevalence at Wharram Percy (39%) (Lewis et al., 1995a) is at the lower end of those from the urban populations

Dental disease may cause up to 40% of maxillary sinusitis in living populations (Simuntis et al., 2014), but there does not appear to be an association between the presence of maxillary sinusitis and underlying dental disease in any of the populations analysed in this study as the prevalence of maxillary sinusitis is similar between skeletons where dental disease was recorded and those where no dental disease was recorded. The presence of maxillary sinusitis was therefore considered the result of environmental factors or disease in this study.

There was a significant difference in the prevalence of periosteal rib lesions between the populations. The 10% prevalence of lesions in Ghent was “dwarfed” by high prevalence rates in Canterbury (63%) and Caen (63%). However, previously reported prevalence rates for this period have often remained below the 10% seen in Ghent (see Figure 6.27). Chichester’s hospital stands out with 20% (Magilton et al., 2008). The methodological and sampling issues that may have contributed to these exceptional prevalence rates for Canterbury and Caen have already been discussed above (see section 6.2 above). In northern France, Sains-en-Gohelle (<1%) (Beauval et al., 2012) and Douai St. Amé (12%). These frequency rates are both significantly lower than the rates reported here for Caen (63%).

Maxillary sinusitis and periosteal rib lesions were both used as an indicator of air pollution in this study. However, despite a high prevalence of maxillary sinusitis and periosteal rib lesions in Ghent and Canterbury, there does not appear to be an association between the occurrence of maxillary sinusitis and periosteal rib lesions within the same skeleton in Caen (χ^2: 1.5432, p=0.21414, df: 1). This indicates that air quality is not the only and that other aetiological factors contribute significantly to the presence of these lesions in these populations (see Chapter 2) Below the circumstances in these towns that may have contributed to high levels of lower respiratory disease, and the difference between the prevalence reported in Ghent and those in the other populations will be explored.

Figure 6.9: CPR of maxillary sinusitis in NW Europe

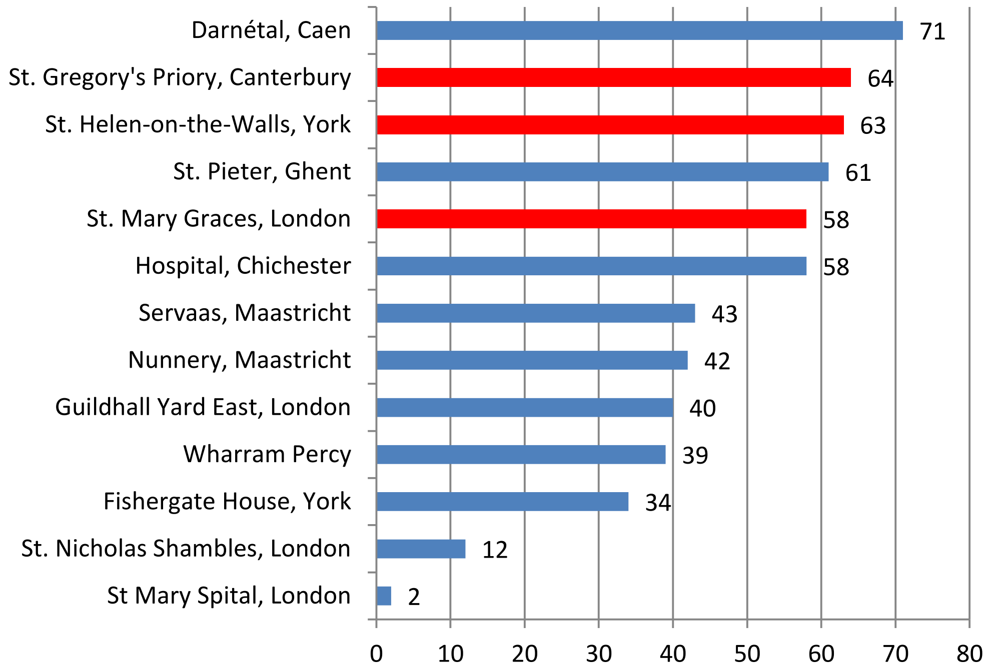
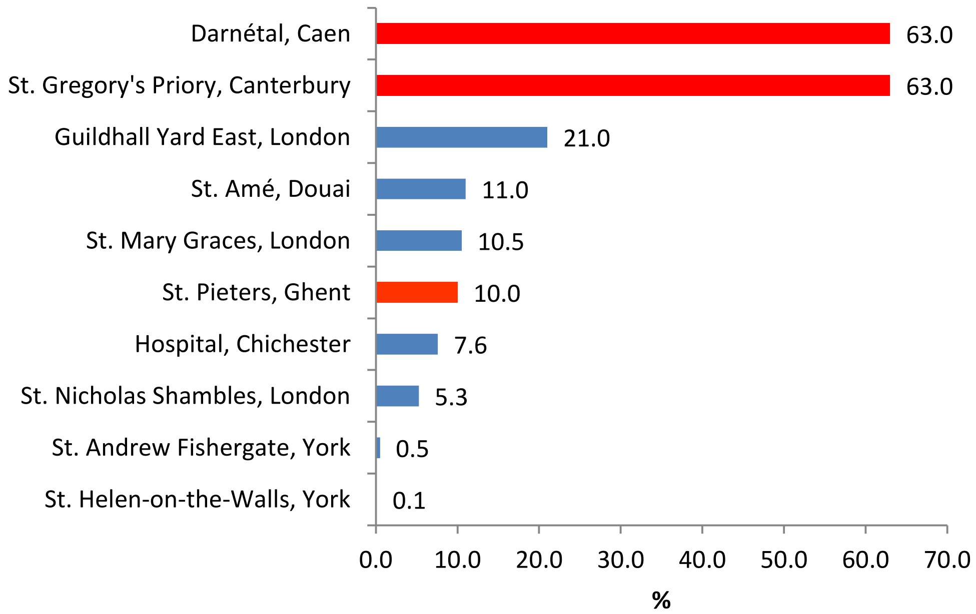


Figure 6.10: CPR of periosteal rib lesions in NW Europe



Maxillary sinusitis and periosteal rib lesions were both used as an indicator of air pollution in this study. However, despite a high prevalence of maxillary sinusitis and periosteal rib lesions in Ghent and Canterbury, there does not appear to be an association between the occurrence of maxillary sinusitis and periosteal rib lesions within the same skeleton.

6.2.4 Summary

Comparing the results from Caen, Canterbury and Ghent with sites from NW Europe has shown that the prevalence rates of skeletal indicators of adaptation were mostly comparable across the sites and data available from other sites. However, the prevalence of non-specific periosteal reaction on the tibiae was significantly higher in Ghent. Furthermore, the prevalence of periosteal reaction on the ribs was significantly higher in Caen and Canterbury compared to previously published sites. However, the prevalence of rib lesions was still relatively high in comparison to previously reported results. These similarities and differences are explored below to address the hypotheses and research questions of this project.

6.3 Health in urban NW Europe

So far this chapter has addressed the limitations of the research and compared the prevalence rates of skeletal indicators from Caen, Canterbury and Ghent with each other and other sites in the region. In this section this evidence is combined with other sources of evidence to interpret them in a wider context.

6.3.1 Socio-economic status

Chapter 2 has shown that socio-economic status can be a more important factor than settlement type in determining health in current populations as wealth is associated with better access to food, goods and services. It is likely that poverty affected at least some people in the populations studied here, either through birth or through circumstance. Van Steensel (2013) estimated up to 50% of the population in urban England may have been affected by poverty at some point during their lifetime. However, every town would have faced a unique set of challenges and would therefore have been affected differently. As a consequence there is no specific pattern of skeletal lesions associated with poverty. In St. Helen-on-the-Walls in York, poverty was associated with a high prevalence rate of cribra orbitalia (68%) and a small average adult stature for both males and females (Grauer 1989). In a study of medieval Poland and Italy the presence of indicators of adaptation was associated with a taller average stature in Giecz, Poland and smaller average stature in Trino Vercellese, Italy (Vercellotti et al, 2014). The socio-economic make-up of the populations under investigation is explored here.

The Darnétal parish in Caen covered up to a quarter of the town (Huard, 1925). The people within the parish are therefore likely to have had different occupations and varied socio-economic backgrounds. However, even the most prosperous in Caen may sometimes have faced hardship. After the growth of Caen from the 11th and 12th century, the town faced decline between the 13th and 16th century as a consequence of instability in the region and a changing political landscape (see Chapter 4). During times of war, the level of poverty would have been higher than in times of peace. Unfortunately, it is not possible to know if and how this affected the results of this study.

In Canterbury, the cemetery of St. Gregory's priory served the St. Mary parish as well as the St. John's hospital for the poor and infirm (Hicks and Hicks 2001). While the socio-economic backgrounds of people living in St. Mary's are not currently known, it is unlikely that the hospital represents the truly poor. St John's hospital categorically refused some subgroups of the population (e.g., the old, the blind) and also provided rooms for some wealthy, healthy individuals (Sweetingburgh, 2010b). Even though the prevalence rates of skeletal indicators from St. Helen-on-the-Walls and Chichester hospital cannot be considered to be the benchmark of poverty and hospital conditions respectively, it is worth noting that the results from Canterbury are less comparable to those sites and more in line with urban populations like Fishergate House in York. The impact of poverty on this population is therefore unclear.

The St Pieter parish in Ghent occupied a special place on the edge of the town. In the 13th century part of the parish was incorporated within the town centre while the rest stayed a suburb until the 14th century (Van Houtryve, 2013). This is also reflected within the parish. The area closest to the town centre was relatively prosperous, while the area further away from the centre was one of the poorest of Ghent (Nicholas, 1987). Unfortunately, it is not known whether the skeletons from this study came from the affluent or poorer part of the parish.

The evidence from these three sites indicates that poverty may have affected each of the populations, but that depending on the personal experience of the people included in this research. Unfortunately, it is not possible to determine how much the results have been affected.

6.3.2 Sanitation

By the 13th century many regions in Europe were trying to improve sanitary conditions in theiurban centres (Clark, 2009). Good sanitation is essential for human health (see Chapter 2). Even today, rapidly expanding cities in developing countries can struggle to provide clean drinking water and an effective waste management system (e.g. Karn and Harada, 2002). In the developing world, the lack of an adequate water supply and inadequate waste management has been linked with outbreaks of diseases such as cholera and dysentery (Simatele and Binns, 2008; WHO, 2011). In this project, poor health was expected to be visible through the indicators of adaptation: reduced male and female stature, as well as a high prevalence of cribra orbitalia, dental enamel hypoplasia, and periosteal reaction on the tibiae As Northern France was slow in the uptake of sanitary measures, it was hypothesised that this would affect the results from Caen.

Comparing the results from Caen with other towns in NW Europe has shown that the results from this study are comparable with other urban populations. Surprisingly, the prevalence rate of periosteal reaction on the tibiae in Ghent was significantly higher than in Caen and Canterbury. This will be explored further below, but first the reason Caen does not differ significantly from other populations is discussed.

It is possible that the differences in sanitary conditions were less significant than they first appear. The standard of sanitation in European towns would have been low in comparison to modern standards (See Chapter 3). Sources of clean water mostly were likely insufficient to serve the entire population of an urban centre. Complex water systems like the one from Christ Church Priory in Canterbury were expensive in upkeep and a challenge to keep access points uncontaminated (Magnusson 2001; Geltner, 2012). Historical sources suggest that in some Italian towns people were employed to guard fountains to prevent people from contaminating the water (Zupko and Laures, 1996). Furthermore, many urban centres struggled to keep the streets clean and at times waste may have accumulated in the streets (Leguay, 1999; Bayless, 2012). Moreover, livestock was reared within towns (Leguay, 1999). Such conditions would have provided excellent circumstances for the spread of disease. Evidence of parasitic infestations have been identified from urban populations across Europe (Carrott et al., 1994; Bouchet et al., 2003; Rocha et al., 2006; De Groote et al., 2008; Kenward, 2009; Ponel et al., 2014). Parasitic infections can lead to a variety of diseases, including nutritional deficiencies (Garcia, 2009), and would not have been the only disease vector. Poor sanitary conditions in childhood could have resulted in cribra orbitalia, dental enamel hypoplasia and/ or reduced adult stature (see Chapter 2). The impact of food availability on nutritional deficiencies is explored in section 6.3.4 below.

Industry would have also strongly affected the sanitary conditions in a town. Every town would have had a variety of industries to supply the settlement with essential and luxury products. Some industries would produce vast amounts of waste and/ or wastewater (e.g. butchers and the textile industry) adding more pressure on the existing infrastructure, while others would use urine and/or faeces (see Chapter 3). In many towns industries were tightly regulated (e.g. Norwich) and those considered most polluting banned to the suburbs (Jørgensen, 2010b). This was certainly the case in Canterbury (Urry, 1967). In Ghent over half of the population worked in textile related industries and this was replicated in the St. Pieter parish (Nicholas, 1992; Clark, 2009; Van Houtryve, 2013). In Caen and Canterbury, occupations would have been more diverse. The textile industry produces lots of waste water (Leguay, 2002a) and is therefore predicted to affect the health of the population in the St Pieter parish in Ghent. The prevalence rates of DEH, and cribra orbitalia are in line with other sites (see section 6.2.2). However, the prevalence of non-specific periosteal reaction on the tibiae is significantly higher than in Caen and Canterbury ($\chi 2$: 18.503, p=>0.001, df: 2). Some industrial processes (e.g. tanning) use chemicals that can cause skin diseases and, as the skin is close to the bone in lower legs, this might contributed to the prevalence rate seen here. However, trauma, infectious disease, and metabolic disease can also lead to periosteal reaction on the tibiae (see Chapter 2 for details). The prevalence of periosteal reaction as a result of infectious disease is explored under migration below.

6.3.3 Air quality

One of the questions this research aimed to answer is whether poor air quality led to high levels of respiratory disease (maxillary sinusitis and periosteal reaction on the ribs) in these populations. The earliest evidence of regulations against air pollution in London stem from the 14th century (Brimblecombe, 1987). The most common source of air pollution was the burning of biomass fuels (timber, peat, organic matter, etc.) for cooking and heating. From the 13th century, coal was transported from Newcastle in northern England to southern England (Rawcliffe, 2013). Coal is, however, a dirty fuel and for a long time it was only used in industry (Brimblecombe, 1975). House fires and some industries (e.g. smiths and bakers) were further sources of air pollution (Clark, 2009). The lower population density in Ghent's suburb was expected to lead to better air quality and thus lower levels of skeletal indicators of respiratory disease.

The prevalence rates of maxillary sinusitis and periosteal rib lesions do not paint a consistent picture. The high prevalence of maxillary sinusitis is comparable across the three sites and is consistent with other sites in the region (see section 6.2.3). If this reflects the air quality in the three populations, this would suggest a highly polluted environment and that the lower population density in Ghent did not equal a better environment than the more centrally located populations from Caen and Canterbury. The prevalence of maxillary sinusitis in rural populations can be as high as those reported in urban environment but the sources of air pollution may be different (Lewis et al., 1995a; Roberts, 2007; Sundman and Kjellström, 2013a).

In Caen and Canterbury the prevalence of periosteal reaction on the ribs (63% in each site) is in line with the maxillary sinusitis evidence. In contrast, rib lesions were only reported in 10% of the Ghent population. While this could be indicative of differences in the urban environment, it should be noted that the prevalence rate from Ghent is already high for late medieval populations. The high prevalence rates in Caen and Canterbury have no comparison. A high prevalence has however, been reported in Neolithic Germany (35%) (Nicklisch, 2012). It seems unlikely that air pollution in Neolithic Germany would have been worse than that in late medieval towns. It is therefore likely that other aetiological factors affected these results. This is further supported by the fact that there is no association in the presence of maxillary sinusitis and periosteal lesions on the ribs in Caen and Canterbury. Chapter 2 has shown that the aetiology of both periosteal rib lesions and maxillary sinusitis are complex. In the bioarchaeological literature, periosteal reaction on the ribs is often discussed in relation to tuberculosis. Infectious diseases in these populations are discussed further in section 6.3.4 (migration) below. Maxillary sinusitis levels do not appear to have been affected significantly by dental disease (see section 6.2.2).

6.3.4 Diet

Nutrition is a function of diet as well as being able to absorb the required nutrients. Section 6.3.2 has shown that parasitic infections were common and may have resulted in nutritional deficiencies. The focus here is therefore on the availability and accessibility of food in urban settlements.

One of the characteristics of the urban environment is that it moves away from agriculture. As a consequence, it has to rely on a supply of food from its hinterland (Beresford, 1967). In Flanders, the population outgrew its potential to grow enough food to sustain its population in the 12th century and relied on imports from further afield (Nicholas 1987). Outside Flanders exotic food was also imported. For example, a study of a reredorter from St John's hospital in Canterbury shows food was imported from continental Europe (Carrott et al., 1994). In normal times, a variety of food stuffs including meat, fish, vegetables and cereals were available for those who could afford it. The diet of the poor was based on vegetable broth and dark bread (Adamson, 2004). As the socio-economic statuses of the people included in this research are unclear, the variability in the diet of individuals in this study remains unknown.

Food was, however, not always easily available. Crop failure would have had devastating effects on the food supply in these late medieval towns and would have occurred fairly regularly (Nicholas, 1992; Mate, 2010a). The Great Famine resulting from crop failures in Europe in 1317-1319 may have killed up to 10% of the population (McMichael, 2012). In Flanders and Normandy the subsequent years may have been equally as bad as storms and flooding were alternated with droughts (Behringer, 2010). Famines were often accompanied by gastro-intestinal disease as food that was not fit for consumption was eaten in desperation (Leguay, 2002a). This is not to say the quality of food was guaranteed in prosperous times. An increase in the storage of grain associated with urbanisation is associated with an increase in grain pests (Kenward, 2009). Furthermore, unscrupulous sellers may have used contaminated ingredients (Leguay, 2002a). It is likely that the food supply was affected by warfare, especially in Caen (Leguay, 2002a).

People who grew up and survived a time of food shortage may have traces of this disruption in their skeleton (DEH, cribra orbitalia, and reduced adult stature). The prevalence of cribra orbitalia is low in all populations (see Figure 6.8). However, Studies of juveniles in late medieval Canterbury and 16th century Caen have shown high levels of nutritional deficiencies (Dawson, 2011; Guillot and Thomann, 2013). This suggests many people who were subjected to stress died before reaching adulthood or that the lesions healed. In Canterbury DEH was recorded in 61% and 43% of those displayed multiple lesions in the same tooth. This shows that the population of Canterbury was resilient in surviving episodes of stress. In Caen, the overall level of DEH was lower (49%), but from those 45% displayed severe DEH. Lastly, in Ghent DEH was present in 52% of individuals, but a much lower proportion (24%) of those showed severe DEH. This might suggest that there was less nutritional stress in Ghent. Ghent's monopoly on grain within the County of Flanders may have given it more access to grain than other towns in times of shortage (Nicholas 1992). On the other hand, if skeletons from the poorer area of the parish are present, it is likely they would have been under high levels of environmental stress.

6.3.5 Migration

Until recently, urban centres required immigration to maintain and grow their population. The majority of these migrants would have come from the local hinterland. While this rural to urban migration can result in the introduction of rural diseases (such as malaria) in the urban population (See Chapter 2), it is more likely that merchants, pilgrims and other people sharing the road between towns were important in the spread of infectious disease from one place to another. The poor sanitary conditions described above (section 6.3.2) then provided the perfect conditions for these conditions to take hold. Canterbury, still famous as a medieval place of pilgrimage through *the Canterbury Tales*, was predicted to be worst affected. After the murder of Archbishop Thomas Becket in the cathedral in the 1170, it became an important centre of pilgrimage for the next three centuries (see Chapter 3 and 4), attracting pilgrims from across Europe (Gelin, 2010). In Flemish towns, a pilgrimage to Canterbury was one of the punishments (Webb 2004). In addition to large numbers of pilgrims, Canterbury was a convenient stop for people travelling from London to the North Sea coast (Gelin, 2010). On the contrary, in war-torn Normandy, extensive emigration has been reported for Caen during the English occupation (1417 to 1450) (Favier, 1970b). At the same time, people from England would have settled in the town and people from the hinterland may have sought refuge (Delente, 2000).

Infectious diseases can lead to the development of periosteal reaction on the bone. Some infectious diseases may leave traces that can be identified in the skeleton (e.g., tuberculosis, treponemal disease, leprosy) (Roberts and Manchester, 2005), but in the majority of cases a specific illness cannot be identified (Klaus, 2014). Periosteal reaction on the tibiae was much more prevalent in Ghent (65%) than in Canterbury (18%) or Caen (35%). On the other hand, periosteal reaction on the ribs is significantly more prevalent in Canterbury (63%) and Caen (63%) than in Ghent (10%). If they are evidence of infectious disease, it suggests diseases affecting the lungs were more common in Canterbury and Caen, while Ghent was more strongly affected by diseases leading to periosteal reaction on the lower legs. This does therefore not point to higher prevalence rates of infectious disease in Canterbury compared to Caen and Ghent. However, the presence of periosteal reaction is not only related to infectious disease and the effects of industry and air quality on these results have already been explored previously. Furthermore, some diseases will not leave a trace in the skeleton.

One famous example of the spread of infectious disease in late medieval Europe is the Black Death. The plague arrived in Italy in 1347 and reached NW Europe the following year, decimating the European population (Dyer, 2005; Clark, 2009). While Caen and Canterbury reported large death tolls, this first wave of the disease does not appear to have affected Flanders as much (Blockmans, 2010). The next wave of the plague in the 1360s did affect Flanders more strongly (Nicholas, 1992). The plague (and other infectious diseases) returned regularly throughout Europe until the 17th century. Historical documents show that mortality crises were common in

Canterbury in the 14th and 15th century (Rawcliffe, 2013) and this would have been the same in other towns.

If Canterbury was more strongly affected by infectious disease due to its status as a pilgrimage centre, then this is not visible in the skeletal indicators used in this research. It is likely that the prevalence of infectious disease was high in all populations considering their poor sanitary conditions (see section 6.3.2).

6.3.6 Urbanisation

In the study of past settlements the ‘urban’ and ‘rural’ environments are often presented in binary opposition (see Chapter 1). However, the St. Pieter parish on the edge of Ghent occupied a space between the urban and rural environment and this dichotomy is therefore reconsidered here.

The St. Pieter parish was partially incorporated in the town in the 13th century and the rest remained a suburb until the 14th century (Nicholas, 1987). The town wall was never extended to incorporate the southern part of the parish and differences remained (Van Houtryve, 2013). Depending on the preferred characteristics, the parish could be considered urban or rural. Furthermore, the parish has been described as relatively rural until the 18th century (Van Houtryve, 2013). The similarities in the results between this population and other urban populations in NW Europe make it tempting to assume that the skeletons in this study came from the more urbanised area. However, previous studies have not found significant differences in health between medieval urban and rural settlements (e.g. Palubeckaité et al., 2002; Ulrich-Bochslerr et al., 2011). Others have reported differences though (e.g. Lewis et al., 1995a; Garcin et al., 2010).

It is worth remembering that to define ‘urban’ and ‘rural’ the differences between these environments are emphasised. Charters and privileges may have been a status symbol and do not necessarily reflect the level of urbanisation (Condron et al 2002). In many of the towns, agriculture may still have played an important part in the economy (Astill, 2009). For example, Urry (1967) suggested many people in Canterbury depended on practising agriculture in the 12th century. A relatively rural urban centre and a densely occupied rural nuclear settlement may therefore have been very similar environments.

Furthermore, urban development is often described as the logical pinnacle of settlement growth and that no settlements failed in the rapid expansion leading up to the 14th century (Astill, 2009). However, the decline of Caen started early in the 13th century as power in Normandy was centralised in Rouen (Jouet, 1981a). The fortunes of the town only improved in the 16th century (Jouet, 1981b). It seems reasonable to expect that health would be adversely affected by this failure. Surprisingly, it does not seem to be reflected in the results from this study. However, it is possible that the majority of skeletons came from the period after the situation improved (see section 6.1.4 above).

In line with the evidence from modern settlement patterns (Chapter 1), the urban – rural binary may be too simplistic to describe the variety of settlements that were developing in medieval Europe. It is important to keep in mind that these settlements were in constant flux and that settlements did not develop all urban characteristics simultaneously. It begs the question at which point in the development of a settlement urbanisation had a recognisable impact on human health. Lewis (2002b) suggested industrialisation may be the key. However, Pinhasi et al (2006) have shown that it is not as simple as that as higher prevalence rates were found in a population from pre-industrial London in comparison to a post-industrial one.

6.4 Conclusion

The aim of this thesis was to provide a comparative picture of urban health in late medieval NW Europe. This chapter has drawn on human bioarchaeological, archaeological and historical evidence to answer the questions and hypotheses set out at the start of this thesis regarding health in Caen, Canterbury and Ghent. The results are summarised here.

First, the possibility of socio-economic status affecting the outcome of the research was first explored as this strongly affects human health and could therefore affect the outcome of this research. In each of the populations poverty may have been present to some degree, and it is not possible to determine how this has affected the individuals included in this research. In Caen, the Darnétal parish was large and diverse and the socio-economic status of individuals would have depended on their occupation as well as the political and economic situation at the time. In Canterbury, St John’s hospital for the poor may not represent the truly poor and in Ghent part of the parish was relatively affluent while another part was very poor.

Sanitary conditions were expected to be especially poor in Caen as Normandy did not develop sanitary measures to the same extent as other European regions. The prevalence rates of the skeletal indicators of adaptation from Caen do not differ significantly from those of the comparative sites. It is possible that the skeletal indicators do not reflect differences that were present. However, it is also likely that the standard of sanitation in European towns was low as most urban centres would have been challenged to provide an adequate supply of clean drinking water for the population and to keep the public spaces clean.

The early specialisation of Ghent in the textile industry was expected to have a negative effect on the sanitary conditions in the town. On the other hand, it was suggested that Canterbury's focus on the pilgrim trade might have resulted in reduced industry. The results from Canterbury do not suggest that conditions would have been better than in urban towns. In Ghent, periosteal reaction on the tibiae was significantly more prevalent than in other towns. It has been suggested that the polluting industrial processes associated with the textile industry may have contributed to these high prevalence rates.

Maxillary sinusitis and periosteal reaction on the ribs were recorded to infer air quality. The hypothesis was that the air quality in suburb of St Pieters would have been better than in Caen and Canterbury. The prevalence rate of maxillary sinusitis in Ghent is, however, comparable to other towns. The prevalence of periosteal lesions on the ribs is significantly lower in this population, but still significant when compared to other sites. Furthermore, a lack of correlation in the presence of rib lesions and maxillary sinusitis suggests other factors would have contributed to the presence of these lesions in these populations.

There was a distinct lack of demographic differences within the populations studied in this project. This does not mean there were no cultural differences between men and women, but may indicate that men and women were exposed to similar environmental conditions.

Lastly, no significant differences between the populations were recorded for the skeletal indicators in this study. As differences between men and women were clearly present in medieval society, it has here been suggested that an urban lifestyle would have exposed man and women to a similar environment.

7.1 Introduction

The main aim of this thesis was to provide a comparative picture of late medieval urban health in North-West Europe. In order to achieve this aim, skeletal material from Caen (Normandy), Canterbury (Kent) and Ghent (Flanders) were examined macroscopically. This final chapter summarises the evidence presented in this work and addresses the hypotheses and questions set out in the introduction (Chapter 1):

7.1.1 Hypotheses

- The relative lack of industry in Canterbury was hypothesised to have a positive impact on health.
- Poor sanitation, frequent warfare, economic collapse and the plague had a negative impact on health in Caen.
- Early industrial specialisation and the suburban nature of the living environment in Ghent led to indoor and outdoor pollution which negatively impacted health

7.1.2 Research questions

- Are there any demographic differences in health within and between the populations?
- Did poor sanitary conditions lead to increased levels of skeletal indicators (dental enamel hypoplasia, cribra orbitalia, periosteal reaction on the tibiae and a shorter stature)?
- Did poor air quality lead to high levels of respiratory disease (maxillary sinusitis and periosteal rib lesions)?
- Do these results reflect the effect of socio-economic status rather than the effects of urbanisation?

7.2 Sanitary conditions

Poor sanitary conditions have a negative impact on human health. As the population of Europe grew exponentially between the 9th and 14th century, larger settlements emerged with a higher population density (Clark 2009). In these settlements there would have been an increased pressure on available infrastructure and resources. Very rapidly urban centres may therefore have faced new challenges in providing a clean environment and by the 13th century towns in many regions would have developed sanitary measures (Clark 2009). Northern France has a reputation for being slow in the uptake of such measures at that time (Angers, 2006) and it was therefore expected that this would have affected the health of Caen's population. Caen did not stand out in comparison to Canterbury, Ghent or other sites. It has therefore been suggested that the overall standard of sanitary conditions throughout the region would have been conducive to the spread of disease. Even if Jørgensen (2010a, 2014) is correct that the reputation of dirty medieval towns has been exaggerated, it is likely that at times the measures failed. Furthermore, towns would not have a limitless supply of clean drinking water (Magnusson, 2001, Leguay, 2002a) and contaminated water would therefore have been used (Magnusson, 2001). Also, faecal matter and urine would have been used in some industries and thus provided a perfect opportunity for disease transmission (Leguay, 2002a).

The development of crafts and industry in the urban environment would have added to the domestic pressures (Leguay, 1999). For example, the textile industry creates large quantities of waste water. As 60% of Ghent's population worked in the textile industry (Nicholas, 1987), this was predicted to affect the health of the population. There does not appear to be an increase in cribra orbitalia or dental enamel hypoplasia, but there was a significantly higher prevalence of periosteal reaction on the tibiae. It has therefore been suggested that processes in the textile industry may have contributed to this high prevalence rate.

7.3 Air quality

Maxillary sinusitis and periosteal reaction on the ribs are not often studied and even less so studied together. Roberts (2007) has previously recommended that they should be studied together to infer air quality in past populations. The use of biomass fuels for cooking, heating and industry were expected to be the main factors in late medieval air pollution (Brimblecombe, 1976; Leguay, 2011). The high prevalence of maxillary sinusitis in Caen (71%), Canterbury (64%), and Ghent (61%) is consistent with a hypothesis of high air pollution, while the results from the periosteal rib lesions are less consistent. Periosteal rib lesions in Canterbury (63%) and Caen (63%) were equally high and this might further support the notion that the air quality in those towns was poor. However, periosteal rib lesions were recorded in only 10% of the skeletons in Ghent. This might suggest better air quality in Ghent, possibly due to its lower population density. However, the high prevalence rates Canterbury and Caen are exceptionally high in relation to previously published rates of these lesions. It is unlikely that the air pollution in Caen and Canterbury would have been significantly worse than that of various sites in London, where the highest prevalence rate is 21% (Bernofsky, 2010).

In line with the results from Bernofsky (2010), this project found no correlation in the occurrence of maxillary sinusitis and periosteal rib lesions within the same skeleton. Even though air quality cannot be disregarded completely as an aetiological factor, other factors are likely to have contributed to the prevalence rates of these lesions in this research. Any illness affecting the lungs could result in periosteal rib lesions (Roberts et al., 1998), and their presence has often been described in relation to tuberculosis in bioarchaeological literature (e.g. Kelley and Micozzi, 1984; Pfeiffer, 1991; Nicklisch et al., 2012) and infectious diseases such as tuberculosis would have been present in late medieval towns (Roberts and Cox, 2003). Maxillary sinusitis also has a complex aetiology including dental disease, infectious disease, allergies and air pollution (Slavin et al., 2005).

7.4 Urbanisation and health

The focus in this project has been on the urban environment only. Nevertheless, in comparing Caen, Canterbury and Ghent this research has contributed to the debate on what it means to be ‘urban’ in late medieval Europe. Each of these towns can be considered urban in their own right. However, when comparing them it shows that they developed completely differently throughout the medieval period. Canterbury is a successful market town (Urry, 1967), while Caen is in decline between the 13th and 15th centuries (Favier 1986a). Furthermore, the location of St Pieter on both sides of the town wall of Ghent (Vanhoutryve, 2013) shows that it is difficult to determine the edge of the urban environment. It also shows that there may have been differences in levels of urbanisation within one settlement. As the environment is very important in human health, the lack of statistically significant differences was unexpected. It begs the question: At which point in the urbanisation process can the effect on human health be recognised?

7.5 Socio-economic status

Socio-economic status may be more important than settlement type in the determination of human health (Brender et al., 2011). Poverty was common in late medieval urban populations and many people may have been affected at least temporarily (Dyer, 2012). In Caen, the cemetery covered a large proportion of the town and the success of the town itself varied dramatically (Angers, 2006). In Canterbury, a hospital for the poor may have contributed to the cemetery population in addition to its use as a parish cemetery (Hicks and Hicks, 2001). Lastly, In Ghent, the area closest to the city centre was reasonably affluent, but the remainder of the parish was very poor (Nicholas, 1987). Poverty will therefore have touched upon the lives of the underlying communities. Unfortunately, there is no distinct pattern of skeletal lesions associated with poverty and the situation of individuals cannot be ascertained. Exceptionally, active cribra orbitalia lesions were recorded in adults in one of the poorest parishes of medieval York (St. Helen-on-the-Walls) (Grauer 1989), but this was not replicated here. The socio-economic status of the individuals therefore remains unknown.

7.6 Demography

Cultural differences between males and females were present in late medieval Europe (Hutton, 2005). However, these differences were not reflected in the skeletal indicators recorded in this project. Pressure on space in urban centres may have exposed men and women to similar environmental conditions, as has previously been suggested for maxillary sinusitis (Roberts 2007). Nevertheless, differences between males and females have previously been identified in some urban sites (e.g. Palubeckaité et al., 2002; Šlaus, 2008; Novak and Slaus, 2010).

7.7 Limitations of the research

The limitations of this research have been discussed in detail in the previous chapter (Chapter 6) and are summarised here. As with all bioarchaeological population studies, biases in the burial, preservation and storage of human remains means it is unlikely that the individual skeletons included in this study represent a cross-section of the living population from which the cemetery populations were derived (Ortner, 1991; Waldron, 1994; Roberts and Manchester, 2005). Preservation affects sample selection as the best preserved skeletons were selected from much larger collections in Caen and Canterbury. Furthermore, when skeletal indicators cannot be observed, this can distort the results as lesions may have been present in the missing element (Waldron, 2009). The preservation of skeletons in Ghent was significantly worse than in Caen and Canterbury. To minimise the effect of preservation, crude as well as true prevalence rates were provided for all skeletal indicators.

Climate change, epidemics and famine would have resulted in peaks of disease and mortality throughout this period (McMichael, 2012). Unfortunately, without more accurate dating it is not possible to know how the skeletons in this study were affected by these factors and there may therefore be temporal differences in the prevalence of lesions in these populations.

It is also impossible to identify specific subpopulations within the cemeteries that may have had a higher or lower risk of disease (Wood et al., 1992). For example, in

Ghent, part of the parish was much poorer than the other side (Nicholas, 1987). As poverty has a negative impact on health, the results will have been affected by the proportion of people came from either side of the parish. The cemetery population in Canterbury is a combination of parishioners and inmates of St. John's hospital (Dawson, 2014). These groups would have had very different life experiences and health. Unfortunately, it is impossible to identify whether the skeletons included in this study came from parishioners or from the hospital population. In skeletons not displaying lesions, it is not possible to distinguish between those who were not subject to a stressor and those who died before developing lesions (Ortner, 2008).

The skeletal lesions present in a skeleton are the result of an accumulation throughout life (Mays, 2010). If a person migrated within his life, then the lesions may have been acquired before migration and there incorporation into a study may therefore not represent the health of the population where they were buried. In late medieval NW Europe, migration from the countryside to urban centres was common as was extensive international trade (Clark, 2009). It is therefore likely that migrants were buried in each cemetery. However, they cannot be identified using macroscopic methods.

Furthermore, the limited number of ways in which bone can respond (additional bone growth or destruction of existing bone), means specific aetiological factors can only rarely be identified and the same prevalence rate in different populations can have different causes (Wood et al., 1992). Historical and archaeological evidence was therefore used to identify factors that may have affected the results in these populations in particular.

7.8 Directions for future research

7.8.1 International research

Historical research regularly crosses modern borders. However, this is often not the case for bioarchaeological research (see Chapter 1). In comparing skeletal collections from across these regions, this project has shown that the differences in sanitary conditions expected from the literature did not result in different prevalence rates of lesions and therefore health in these populations. The European Module of the Global History of Health Project (http://global.sbs.ohio-state.edu/global.php) will in future provide comparable data from England and northern France, but no bioarchaeologists from Belgium are involved in this project.

7.8.2 Urbanisation of late medieval Europe

This thesis has focused on three urban settlements within NW Europe. However, to fully understand the effect of urbanisation on health, the health of town dwellers needs to be compared with health in rural populations. For example, a comparison of stature estimates from Caen with a local rural site (Sains-en-Gohelle), shows a 2cm difference in male stature (see Chapter 6). Collections from a rural environment are also available in England (e.g. the Yorkshire village of Wharram Percy) (for multiple examples of rural sites, see Roberts and Cox, 2003).

In addition, the urban development of Flanders in the late medieval was second to Italy. The largest towns in Italy reached more than a hundred thousand inhabitants when towns in NW would have been a few 10,000 at most (Hubert, 2004). Furthermore, Italy has been credited with being the frontrunners in adopting sanitary measures (Ciecieznski, 2013). A comparison of health in NW Europe with Italy may provide further insights on the impact of urbanisation on health in past populations.

7.8.3 Bioarchaeology in Belgium

The development of bioarchaeology (or physical anthropology) in Belgium is in its infancy, with only a handful of researchers working in the field (see Chapter 1). However, skeletal collections may be curated by museums and other institutions. A database of these collections could encourage international researchers with an interest in the urbanisation of in late medieval Europe or the region to incorporate them in their research and thus expand our knowledge of health and disease in this region.

7.8.4 Periosteal rib lesions

The unparalleled high prevalence of rib lesions in Caen and Canterbury has been the most surprising outcome of this research. Further research is required to understand if this is truly as exceptional as it appears. More data on rib lesions is therefore necessary to understand the variability in prevalence for this time period, as an indicator of poor air quality, and this is especially the case for France and Belgium, where very limited data are available for comparison.

Furthermore, in order to make the data more comparable, it would be advisable to develop more guidelines on the recording of these lesions. At the moment some studies will include the nodules of new bone that are sometimes found on the rib surfaces, while others ignore them (Nicklisch et al., 2012). As long as the aetiology of these nodules is not understood, recording their presence clearly will make future comparisons more useful when the aetiology of these lesions is better understood. Guidelines for the recording of rib lesions should consider the following:

- **The preservation of the rib cage**: the number of ribs preserved on left and right sides, but also the proportion of each rib present
- **The side and surface of the rib cage affected**: left/right as well as external or visceral/internal
- **The type of** periosteal lesion present: bone formation or destruction
- **The type of bone formation**: woven, lamellar or mixed.
- **The extent of the lesion:** focal or diffuse.
- **The presence of nodules of new bone**: whether a single nodule on a single rib is included as a minimum
- **Evidence of trauma on the ribs**: if present, the ribs must be excluded because new bone formation may be a response to the healing process of a fracture

These recommendations are based on previous recommendations for the recording of pathological lesions and periosteal reaction in the skeleton (Roberts and Connell, 2004), with an extra focus on the issues involving rib lesions. As a consequence, some studies of rib lesions already provide some of this information (e.g., Santos and Roberts, 2006; Bernofsky, 2010; Nicklisch et al., 2012).

Finally, the aetiology of these lesions should be explored further. Some studies have already investigated the link between the presence of rib lesions and TB (Kelley and Micozzi, 1984; Roberts et al., 1994; Santos and Roberts, 2001), but studies of ancient DNA have so far been unsuccessful in identifying evidence of TB in skeletons with rib lesions (Mays et al., 2002; Nicklisch et al., 2012).

7.8.5 The Black Death in Flanders

The Black Death caused high mortality throughout Europe in the 1340s (Clark, 2009; Büntgen et al., 2011). Caen and Canterbury were badly affected (Lincoln, 1955; Jouet, 1981a). Despite being one of the most densely occupied areas of Europe at the time, Flanders appears to have come through this first wave of the disease relatively unscathed, as estimates put the death toll at 15-25% (Nicholas, 1992). It is currently unknown why Flanders was not affected more by the first wave of the plague when France, England and Germany were badly affected (Nicholas, 1992; van Bavel, 2010). Flanders was, however, affected much more severely in subsequent episodes of the plague, most notably in the 1360s (Nicholas, 1992).

7.9 Concluding remarks

This thesis has provided a unique comparative picture of health in late medieval towns in NW Europe through the analysis of previously unstudied collections from Caen (Normandy, France), Canterbury (Kent, England) and Ghent (Flanders, Belgium). It has shown that the reputation of poor sanitary conditions in northern France did not translate into higher prevalence rates of skeletal indicators of adaptation. It has therefore been suggested that differences in sanitary conditions were relatively small across the region. Nevertheless, industrial processes from the textile industry in Ghent may have contributed to a high prevalence of periosteal reaction on the tibiae.

High prevalence rates of maxillary sinusitis and periosteal reaction on the ribs suggest significant levels of air pollution. However, as they are not significantly associated within the same skeleton, it also highlights the complexity of their aetiology. Unusually high prevalence rates of periosteal reaction on the ribs were reported for Caen and Canterbury. However, there are few comparative sites and it has been recommended that standards are developed for the recording of these lesions.

Lastly, the differences between these populations has challenged the validity of an urban-rural dichotomy and reveals the potential for further work on the complexity of settlements in past populations.

Appendix A: Dating phases in the cemetery of Darnétal, Caen

skeleton ID	Phase	date (in centuries AD)
DAR055	III	15th-18th
DAR062	III	15th-18th
DAR084	III	15th-18th
DAR106	III	15th-18th
DAR117	III	15th-18th
DAR126	III	15th-18th
DAR131	III	15th-18th
DAR132	III	15th-18th
DAR136	III	15th-18th
DAR146	II	12th-14th
DAR167	III	15th-18th
DAR173	III	15th-18th
DAR198	III	15th-18th
DAR206	III	15th-18th
DAR209	III	15th-18th
DAR216	III	15th-18th
DAR217	III	15th-18th
DAR222	III	15th-18th
DAR227	II	12th-14th
DAR238	III	15th-18th
DAR241	II	12th-14th
DAR246	III	15th-18th
DAR253	III	15th-18th
DAR254	III	15th-18th
DAR282	III	15th-18th
DAR292	III	15th-18th
DAR294	III	15th-18th
DAR313	II	12th-14th
DAR318	III	15th-18th
DAR327	III	15th-18th
DAR328	IIIb	1474-18th
DAR331	IIIb	1474-18th
DAR335	III	15th-18th
DAR350	IIIb	1474-18th
DAR360	III	15th-18th
DAR376	III	15th-18th
DAR382	III	15th-18th
DAR392	III	15th-18th
DAR399	IIIb	1474-18th
DAR403	IIIb	1474-18th
DAR419	IIIb	1474-18th
DAR426	II	12th-14th

skeleton ID	Phase	date (in centuries AD)
DAR428	II	12th-14th
DAR440	III	15th-18th
DAR444	II	12th-14th
DAR449	II	12th-14th
DAR462	III	15th-18th
DAR469	II	12th-14th
DAR470	IIIb	1474-18th
DAR487	III	15th-18th
DAR494	III	15th-18th
DAR496	III	15th-18th
DAR503	IIIb	1474-18th
DAR517	III	15th-18th
DAR520	IIIb	1474-18th
DAR533	III	15th-18th
DAR542	III	15th-18th
DAR557	IIIb	1474-18th
DAR558	IIIb	1474-18th
DAR561	IIIb	1474-18th
DAR566	IIIb	1474-18th
DAR575	IIIb	1474-18th
DAR576	IIIb	1474-18th
DAR585	II	12th-14th
DAR587	IIIb	1474-18th
DAR591	III	15th-18th
DAR603	III	15th-18th
DAR611	IIIb	1474-18th
DAR619	III	15th-18th
DAR621	III	15th-18th
DAR626	III	15th-18th
DAR634	IIIb	1474-18th
DAR641	III	15th-18th
DAR649	III	15th-18th
DAR651	III	15th-18th
DAR663	III	15th-18th
DAR701	III	15th-18th
DAR713	III	15th-18th
DAR720	III	15th-18th
DAR755	III	15th-18th
DAR763	IIIb	1474-18th
DAR773	IIIb	1474-18th
DAR774	IIIb	1474-18th
DAR782	IIIb	1474-18th
DAR792	IIIb	1474-18th
DAR803	IIIb	1474-18th

skeleton ID	Phase	date (in centuries AD)
DAR808	IIIb	1474-18th
DAR814	IIIb	1474-18th
DAR815	III	15th-18th
DAR829	III	15th-18th
DAR838	IIIb	1474-18th
DAR845	III	15th-18th
DAR860	IIIb	1474-18th
DAR865	III	15th-18th
DAR874	III	15th-18th
DAR883	IIIb	1474-18th
DAR885	III	15th-18th
DAR887	III	15th-18th
DAR889	IIIb	1474-18th
DAR896	IIIb	1474-18th

The raw data from this research is included on the disc provided with this thesis.

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